JOURNAL OF AGRICULTURAL RESEARCH

VOL. 63 WASHINGTON, D. C., NOVEMBER 15, 1941 NO. 10

EFFECT OF DIFFERENT SOIL COLLOIDS ON THE TOXICITY OF SODIUM SELENITE TO MILLET [1]

By P. L. GILE, *senior chemist*, and H. W. LAKIN, *associate chemist, Division of Soil Chemistry and Physics, Bureau of Plant Industry, United States Department of Agriculture*

INTRODUCTION

In a previous study it was shown that the toxicity of sodium selenate for millet and wheat is very little affected by different soil colloids (*7*).[2] It was pointed out, however, that the results obtained with sodium selenate should not be taken as applying to other forms of selenium, since preliminary experiments indicated that the selenite ion behaves quite differently from the selenate. The results reported in this paper deal with the effects of different soil colloids on the toxicity of sodium selenite.

METHODS

The toxicity of sodium selenite was measured chiefly by the growth of foxtail millet (*Setaria italica* (L.) Beauv.), although some experiments were conducted with Marquis wheat (*Triticum aestivum* L.) and with rice (*Oryza sativa* L.). The plants were grown in pure quartz sand and in mixtures of soil and sand containing usually 1 percent of colloidal soil material. Quantities of sodium selenite near the quantity required to reduce the yield one-half were applied to the two mediums, and the exact quantity of selenite required for half injury was determined from a graph of yields plotted against selenite applications. The value for quartz sand subtracted from the value for a sand-soil mixture gave a figure representing the effect of the soil application on selenite toxicity. As in previous publications (*6*, *7*), this effect of the soil was assumed to be due to the colloidal material present.

The fertilizer mixture added to each 1-gallon pot containing about 5 kg. of quartz sand or sand-soil mixture was 0.93 gm. of potassium nitrate, 0.33 gm. of ammonium sulfate, 0.0185 gm. of ferric tartrate, 0.42 gm. of magnesium chloride ($MgCl_2.6H_2O$), 0.085 gm. of sodium chloride, 0.0015 gm. of manganese sulfate ($MnSO_4.2H_2O$), and quantities of monocalcium phosphate that varied according to the estimated capacities of the soil for rendering phosphate unavailable (*5*). In most of the experiments 0.12 part per million of copper, 0.06 p. p. m. of zinc, and 0.1 p. p. m. of boron were also added. These salts, as well as the sodium selenite, were dissolved in the 750 cc. of water making up

[1] Received for publication May 27, 1941.

[2] Italic numbers in parentheses refer to Literature Cited, p. 580.

the water content of the pot and added to the top of the pot. The fertilizer added to the whole soils in experiments 1, 2, and 3 was 1.40 gm. of potassium nitrate, 0.33 gm. of ammonium sulfate, 0.136 gm. of ammonium chloride, and the variable quantities of calcium monophosphate expressed as P_2O_5 shown in table 1.

Data regarding the soils used in this study are given in previous publications as follows: Nos. 188 to 392 (*8*, *15*); Nos. 6678 to 8736 (*12*); 9475 and B407 (*13*); 9804 and 9805 (*4*); B1086 (*2*); C799 to C805, C1478, and C1479 (*1*); C913, C1672, and C1673 (*3*); C2917 and C2918 (from the same location as Nos. 10083 and 10084, respectively), and C2929 and C2930 (from the same location as Nos. 10305 and 10306) (*4*). Soils C3175 and C3177 are described in a forthcoming publication.[3]

PRELIMINARY EXPERIMENTS

In preliminary work a few experiments were conducted with whole soils and with quartz sand. The results are given in table 1.

The results show that sodium selenite is highly toxic in quartz sand but relatively nontoxic in whole soils. Only 0.0014 gm. of selenium as selenite per pot was required to produce half injury in quartz sand; whereas in the Chester, Vernon, and Muskingum soils, 0.0100 gm. of selenium produced no injury whatever, and in the Kirvin B soil even 0.0800 gm. had no effect on growth. In the Colby soil, however, 0.0068 to 0.0100 gm. of selenium was sufficient to reduce growth one-half. Quite different results were obtained in previous work with sodium selenate. The selanate was only a little less toxic in whole soils than in quartz sand. The average half-toxicity value for 14 whole soils was 0.0066 and for quartz sand in the same experiments, 0.0042. Although soils have no appreciable capacity for fixing the selenate ion, they evidently have a considerable capacity for fixing selenite.

In none of these experiments was there any evidence of growth being stimulated by sodium selenite.

Seemingly sodium selenite is more toxic in quartz sand than sodium selenate. In these experiments 0.0014 gm. of selenium as selenite per pot produced half injury in quartz sand as compared with 0.0044 gm. of selenium as selenate, found in previous work (*7*). However, the toxicity of the selenate varies markedly with the sulfate supply (*7*, *10*). An experiment was therefore conducted to see whether selenite toxicity is likewise affected by the sulfate concentration. In this experiment Marquis wheat was grown in quartz sand, eight plants per pot; the sulfate supply was varied by substituting ammonium sulfate in the standard fertilizer. The quantity of monocalcium phosphate applied was equivalent to 0.20 gm. of phosphorus per pot. The results are shown in table 2.

[3] ANDERSON, M. S., KEYES, MARY G., and CROMER, GEORGE W. SOLUBLE MATERIAL OF SOILS IN RELATION TO THEIR CLASSIFICATION AND GENERAL FERTILITY. U. S. Dept. Agr. Tech. Bul. 813. [In press.]

TABLE 1.—*Effect of different whole soils on toxicity of sodium selenite to millet*

EXPERIMENT 1 (MAY 24-JUNE 18)

Soil sample No.	Kind of soil	Depth	$CaCO_3$ applied per pot	P_2O_5 applied per pot	Sodium selenite added per pot (expressed as Se)	Air-dry yield per pot of plants above ground: Series A	Series B	Series C	Average	Se per pot required to reduce yield of plants by one-half
		Inches	*Grams*	*Grams*	*Gram*	*Grams*	*Grams*	*Grams*	*Grams*	*Gram*
.....	Quartz sand	.....	0	0.20	0	4.36	3.94	3.78	4.03	(1)
					.0050	.19	.15	.16	.17	
					.0100	.06	.04	.06	.05	
300	Chester loam	0–8	2.0	2.00	0	4.46	4.83	4.11	4.47	.....
					.0050	4.24	4.63	4.55	4.47	.....
					.0100	4.07	4.45	4.96	4.49	.....
6719	Vernon fine sandy loam.	0–10	0	.40	0	4.77	4.76	4.60	4.71	.....
					.0050	4.42	4.50	4.43	4.45	.....
					.0100	4.60	4.44	4.05	4.36	.....
6842	Colby silty clay loam.	2–10	0	.20	0	5.97	7.57	7.88	7.14	0.0068
					.0050	4.14	4.26	5.21	4.54	
					.0100	1.98	1.58	2.14	1.90	

EXPERIMENT 2 (SEPT. 1–24)

.....	Quartz sand	.....	0	0.20	0	3.10	3.29	3.09	3.16	0.0014
					.0015	1.60	1.40	1.40	1.47	
					.0040	.31	.35	.25	.30	
B407	Muskingum silt loam.	0–7	2.0	.27	0	5.70	5.71	6.09	5.83	.....
					.0050	5.78	5.74	5.05	5.52	.....
					.0100	5.64	5.65	5.80	5.70	.....
6679	Kirvin fine sandy loam.	12–24	2.0	2.66	0	3.18	3.60	3.44	3.41	.....
					.0400	3.75	3.62	3.12	3.50	.....
					.0800	3.13	3.87	3.02	3.34	.....
6678	....do.....	0–12	0	.67	0	3.70	3.78	3.44	3.64	.....
					.0200	3.35	3.47	3.43	3.42	.....
					.0400	3.25	3.10	3.86	3.40	.....

EXPERIMENT 3 (OCT. 12–NOV. 13)

.....	Quartz sand	.....	0	0.20	0	2.00	2.31	2.63	2.31	0.0012
					.0015	.82	.79	.85	.82	
					.0040	.14	.16	.10	.13	
6842	Colby silty clay loam.	2–10	0	.20	0	3.80	4.02	4.68	4.17	.0100
					.0050	3.57	2.91	3.54	3.34	
					.0100	2.31	1.94	1.99	2.08	

[1] The half-toxicity value is something less than 0.0026. The true value cannot be determined from the data because of the curvature of the toxicity curve and interpolation between distant points.

TABLE 2.—*Influence of sulfate on toxicity of sodium selenite to wheat in quartz sand*

SO_4 applied per pot	Sodium selenite added per pot (expressed as Se)	Air-dry yield per pot of plants above ground: Series A	Series B	Series C	Average	Average air-dry yield of roots per pot	Se per pot required to reduce yield of plants above ground by one-half	Se in air-dry plants and limit of error of determination: Tops	Roots
Gram	*Gram*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Gram*	*P. p. m.*	*P. p. m.*
0.240	0	3.27	2.37	2.83	2.83	1.09	0.0032	210±20	440±40
	.0020	2.11	2.13	2.00	2.08	.84		260±40	810±60
	.0040	.85	.89	.95	.90	.54			
.120	0	3.03	3.19	3.42	3.21	1.15	.0024	100±20	540±40
	.0020	1.84	1.88	1.88	1.87	.86		370±40	830±50
	.0040	.65	.95	1.10	.90	.60			
.024	0	2.48	3.55	3.44	3.16	1.27	.0025	160±20	320±40
	.0020	2.05	1.66	1.77	1.83	.84		400±40	820±70
	.0040	.64	.76	.83	.74	.49			

In this experiment the selenite required for half injury is constant within the limits of experimental accuracy for fivefold and tenfold variations in the sulfate supply. Evidently selenite toxicity is affected little or not at all by the sulfate concentration, at least so long as the supply is sufficient for normal growth. Nevertheless, it is possible that the injury produced by selenite, as well as by selenate, may be due to an insufficiency of sulfur in the plant.

An experiment was also conducted to see whether toxicity of the selenite is influenced by the phosphate supply. This was necessary, since in subsequent experiments the phosphate applications to different sand-soil mixtures were varied according to the estimated capacities of the soils for phosphate fixation. Also, one might expect an antagonism between phosphate and selenite. The results of the experiment, conducted with millet grown in quartz sand and in two sand-soil mixtures, are shown in table 3.

The toxicity values for high and low phosphate applications are the same, within experimental error, in quartz sand and in the Marshall soil-sand mixture. In the Cecil soil-sand mixture it apparently takes more selenite to reduce the yield one-half with the lowest phosphate application than it does with the two higher phosphate applications. It will be noted that the lowest phosphate application in the Cecil soil-sand mixture was not sufficient for maximum growth in that mixture. It may be concluded that the toxicity value for sodium selenite does not vary with the phosphate supply so long as this is sufficient for maximum growth. Similar results were obtained previously with sodium selenate (*7*) and calcium arsenate (*6*).

SPECIFIC EFFECTS OF SOIL COLLOIDS ON SELENITE TOXICITY

The effect of different soil colloids on selenite toxicity was determined in sand-soil mixtures that contained sufficient soil to supply 50 gm. of colloid per pot, equivalent to about 1 percent of the sand-soil mixture. Millet was grown in all experiments except one in which Marquis wheat was the crop plant. The results are shown in table 4. The weight of the roots was recorded in order that the selenium absorbed by the plant might be determined; but only the weight of tops (the part of the plant above ground) was used in estimating the quantity of selenite that reduced growth one-half.

The half-toxicity values (selenium required to reduce the yield one-half) given in table 4 are those obtaining in quartz sand or in sand-soil mixtures. By subtracting the sand value from that of the sand-soil mixture, a half-toxicity value is obtained which represents the effect of 50 gm. of colloid per pot or of 1 percent of soil colloid. These specific values, expressed as grams of selenium per pot, are shown in table 5. Data in tables 3 and 7 as well as in table 4 were used in compiling this table. Values given for the Colby, Marshall, Cecil, and Kirvin soils are averages of duplicate determinations.

TABLE 3.—*Influence of phosphate on toxicity of sodium selenite to millet in quartz sand and sand-soil mixtures*

Soil sample No.	Kind of soil mixed with quartz sand	Depth	P_2O_5 applied per pot	Sodium selenite applied per pot (expressed as Se)	Air-dry yield per pot of plants above ground					Average air-dry yield of roots per pot	Se per pot required to reduce yield of plants above ground by one-half	Se in air-dry plants and limit of error of determination	
					Series A	Series B	Series C	Series D	Average			Tops	Roots
		Inches	*Grams*	*Gram*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Gram*	*Gram*	*P.p.m.*	*P.p.m.*
.....	Quartz sand only.....	.....	0.20	0	0.93	1.10	1.39	1.21	1.16	0.18	0.0012	120±20	200± 50
				.0013	.48	.52	.59	.57	.54	.10			
			.40	0	1.09	1.14	1.08	1.09	1.10	.18	.0017	110±20	420±100
				.0013	.58	.77	.71	.64	.68	.12			
8736	Marshall silt loam.....	0–13	.30	0	1.20	.....	1.37	1.45	1.34	.15	.0041	50±10	240± 50
				.0038	.63	.....	.77	.79	.73	.10			
			.60	0	.....	1.48	1.19	.....	1.34	.15	.0045	30±10	80± 30
				.0038	.69	.73	.87	.....	.76	.09			
6977	Cecil sandy clay loam.....	0–6	.40	0	1.17	.80	1.00	1.18	1.04	.15	.0080	20± 5	350± 80
				.0092	.49	.44	.45	.41	.45	.09			
			.80	0	1.33	1.48	1.42	1.79	1.51	.22	.0062	80±20	670±140
				.0092	.38	.50	.29	.32	.37	.08			
			1.20	0	1.45	1.63	1.68	1.78	1.64	.22	.0058	70±10	690±140
				.0092	.31	.46	.32	.28	.34	.07			

TABLE 4.—*Effect of different soil colloids on toxicity of sodium selenite to plant growth in sand-soil mixtures*

[Millet grown except as otherwise indicated]

Soil sample No.	Kind of soil mixed with quartz sand	Depth	P_2O_5 applied per pot	Sodium selenite added per pot (expressed as Se)	Air-dry yield per pot of plants above ground				Average air-dry yield of roots per pot	Se per pot required to reduce yield of plants above ground by one-half	Se in air-dry plants and limit of error of determination	
					Series A	Series B	Series C	Average			Tops	Roots
		Inches	*Gram*	*Gram*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Gram*	*P. p. m.*	*P. p. m.*
	Quartz sand only		0.20	0	2.12	2.17	2.25	2.18		0.0013		
				.0015	.83	.87	.87	.86				
				.0040	.13	.13	.15	.14				
6678	Kirvin fine sandy loam	0–12	.40	0	2.59	2.19	2.60	2.46		.0183		
				.0150	1.22	1.33	2.08	1.54				
				.0300	.11	.08	.05	.08				
B407	Muskingum silt loam	0– 7	.20	0	3.02	3.05	2.88	2.98		.0060		
				.0050	1.43	1.73	1.78	1.65				
				.0100	1.15	.60	.79	.85				
				.0200	.02	.04	.03	.03				
C813	Manor loam	1– 8	.30	0	2.08	2.02	1.92	2.01		.0066		
				.0100	.52	.32	.63	.49				
				.0200	.05	.02	.02	.03				
6842	Colby silty clay loam	2–10	.20	0	1.05	1.04	1.33	1.14		.0038		
				.0025	.96	.60	.97	.84				
				.0050	.25	.33	.32	.30				
	EXPERIMENT 7 (SEPT. 9–OCT. 5)											
	Quartz sand only		0.20	0	2.27	2.55	2.55	2.46	0.65	0.0015	120± 20	700± 70
				.0013	1.50	1.25	1.30	1.35	.48		270± 70	540±130
				.0026	.42	.43	.62	.49	.25			
8736	Marshall silt loam	0–13	.20	0	5.17	5.49	5.33	5.33	1.41	.0038	30± 10	140± 40
				.0025	3.67	3.89	3.78	3.78	.91		80± 20	250± 70
				.0050	1.40	1.48	1.99	1.62	.46			
6977	Cecil sandy clay loam	0– 6	.40	0	3.10	2.99	2.74	2.94	.60	.0092	70± 20	440± 60
				.0070	2.60	1.66	1.66	1.97	.53		90± 20	330± 50
				.0140	.50	.23	.36	.36	.15			
9475	Nacogdoches fine sandy loam	0– 8	.50	0	3.62	4.65	4.40	4.42	.93	.0108	90± 20	290± 60
				.0100	2.27	1.89	2.67	2.28	.57		330±100	720±100
				.0200	.05	.03	.01	.03	.04			
B1086	Spearfish silt loam	0–12	.30	0	4.78	4.94	5.09	4.94	1.23	.0049	40± 10	190± 30
				.0030	3.78	3.30	3.96	3.68	1.05		110± 20	890± 70
				.0060	1.69	2.20	1.49	1.79	.48			

EXPERIMENT 6 (OCT. 31–DEC. 11)

EXPERIMENT 8 (SEPT. 25–NOV. 2)

----	Quartz sand only	----	0.20	0	4.81	4.40	4.03	4.41	0.88	0.0015	----	----
				.0013	2.35	2.78	2.11	2.41	.65		70± 10	300± 50
				.0026	.93	1.00	1.03	.99	.38		70± 30	970± 90
6679	Kirvin fine sandy loam	12–24	.40	0	2.90	3.14	2.88	2.97	.57	.0065	----	----
				.0100	.70	.66	.70	.89	.17		50± 10	490±100
				.0200	.03	.02	.03	.03	.01		900±300	----
6719	Vernon fine sandy loam	0–10	.30	0	4.93	6.15	6.12	5.73	1.12	.0046	----	----
				.0040	3.33	3.26	3.28	3.29	.73		80± 10	370± 50
				.0080	.32	.17	.31	.27	.11		90± 30	900±300
305	Stockton clay adobe	0–38	.20	0	5.37	5.33	5.37	5.36	1.07	.0041	----	----
				.0015	4.32	4.77	4.19	4.43	.88		25± 5	080± 20
				.0030	3.25	3.55	3.44	3.41	.65		70± 10	360± 50
188	Orangeburg fine sandy loam	10–36	.40	0	3.07	4.40	4.02	3.83	.87	.0051	----	----
				.0060	1.50	1.47	1.80	1.59	.42		80± 20	400± 80
				.0120	.13	.17	.25	.18	.10		270± 90	1200±350

EXPERIMENT 9 (OCT. 25–NOV. 29)

----	Quartz sand only	----	0.20	0	2.04	2.27	2.84	2.38	0.41	0.0018	----	----
				.0013	1.42	1.50	1.53	1.48	.32		110±20	200± 50
				.0026	.68	.62	.72	.67	.19		170±50	600± 80
392	Hagerstown loam	8–30	.40	0	3.98	3.65	3.44	3.69	.54	.0032	----	----
				.0040	1.45	1.30	1.41	1.39	.28		120±20	350±100
				.0080	.65	.45	.49	.53	.15		190±60	440±100
----	Nipe	15–26	.54	0	.33	.57	.32	.41	.07	----	----	----
				.0100	.37	.34	.30	.34	.07		40±10	320± 90
				.0200	.01	.08	.08	.06	.04		180±60	360± 90
198	Sassafras silt loam	8–22	.40	0	3.48	3.56	3.49	3.51	.55	.0062	----	----
				.0040	3.14	3.18	2.24	2.85	.47		40±10	140± 40
				.0080	.50	.88	.96	.78	.16		180±20	630±200
195	Clarksville silt loam	0–10	.30	0	3.74	2.76	3.48	3.33	.52	.0046	----	----
				.0030	2.06	2.38	2.32	2.26	.43		90±10	230± 50
				.0060	1.01	1.32	1.33	1.22	.24		80±20	280±100

TABLE 4.—*Effect of different soil colloids on toxicity of sodium selenite to plant growth in sand-soil mixtures*—Continued

EXPERIMENT 10 (OCT. 16–NOV. 29)

Soil sample No.	Kind of soil mixed with quartz sand	Depth	P_2O_5 applied per pot	Sodium selenite added per pot (expressed as Se)	Air-dry yield per pot of plants above ground				Average air-dry yield of roots per pot	Se per pot required to reduce yield of plants above ground by one-half	Se in air-dry plants and limit of error of determination	
					Series A	Series B	Series C	Average			Tops	Roots
		Inches	*Gram*	*Gram*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Gram*	*P. p. m.*	*P. p. m.*
.....	Quartz sand only		0, 20	0	2. 53	2. 39	2. 77	2. 56	0. 57	0. 0017	.....	.....
				.0013	1. 29	1. 49	1. 80	1. 53	.41		44±10	490± 80
				.0026	.54	.62	.55	.57	.21		12± 5	480±160
C804	Hagerstown silt loam	3–12	.40	0	3. 75	3. 60	3. 15	3. 50	.61	.0050	.....	.....
				.0040	2. 53	1. 75	2. 22	2. 17	.43		11± 4	80± 15
				.0080	.60	.52	.47	.53	.14		50±10	.....
C805	do	12–33	.40	0	3. 08	3. 00	3. 01	3. 03	.49	.0040	.....	.....
				.0040	1. 47	1. 33	1. 60	1. 47	.35		45±10	.....
				.0080	.13	.25	.20	.19	.12		.....	680±150
C799	Hagerstown silty clay loam	2– 8	.40	0	4. 02	3. 56	4. 25	3. 94	.63	.0068	.....	.....
				.0040	3. 45	2. 78	3. 41	3. 21	.59		15± 5	80± 15
				.0080	1. 38	1. 03	1. 81	1. 41	.29		24± 5	170± 30
C800	do	8–14	.40	0	3. 72	3. 63	3. 56	3. 64	.62	.0042	.....	.....
				.0040	1. 98	1. 73	1. 95	1. 89	.41		32± 5	80± 15
				.0080	.43	.23	.37	.34	.11		60±20	440±100
C1672	Chester loam	10–34	.40	0	2. 32	2. 14	1. 98	2. 15	.45	.0067	.....	.....
				.0040	1. 91	1. 46	1. 70	1. 69	.36		30± 5	140± 30
				.0080	.83	.72	.81	.79	.20		12± 4	200± 40
C1673	do	34–60	.40	0	1. 83	1. 72	1. 47	1. 67	.32	.0070	.....	.....
				.0040	1. 58	1. 55	1. 33	1. 49	.33		35±10	100± 20
				.0080	.61	.60	.64	.62	.15		50±10	340± 60

EXPERIMENT 11 (FEB. 28–APR. 1)

.....	Quartz sand only	.....	0.20	0	3.80	3.32	3.35	3.49	0.60	0.0022	.....	.....
				.0013	2.55	2.52	2.85	2.64	.49		20±5	170± 30
				.0026	1.44	1.25	1.51	1.40	.32		30±5	130± 40
C2917	Carrington loam	3–13	.25	0	8.68	8.70	9.05	8.81	1.71	.0064	.....	.....
				.0035	5.92	6.40	6.44	6.25	1.12		8±2	45± 10
				.0070	3.72	4.67	3.86	4.08	.56		30±5	270± 30
C2918	do	13–22	.25	0	6.90	7.60	7.36	7.29	1.13	.0060	.....	.....
				.0035	5.94	5.83	5.72	5.83	1.29		8±2	18± 6
				.0070	2.25	3.22	2.82	2.76	.46		35±5	110± 20
9804	Columbiana clay	0–10	.40	0	6.88	6.78	6.43	6.70	1.45	.0059	.....	.....
				.0045	4.07	4.18	4.18	4.14	.55		20±5	80± 20
				.0090	1.33	1.36	2.11	1.60	.37		20±5	720±100
9805	do	10–25	.40	0	6.30	5.58	6.12	6.00	1.08	.0057	.....	.....
				.0045	3.58	3.73	3.75	3.69	.88		18±3	270± 40
				.0090	1.25	1.13	.90	1.09	.27		25±5	1,460±120
C2929	Barnes loam	0– 9	.20	0	7.18	6.80	6.37	6.78	.89	.0042	.....	.....
				.0025	5.30	5.96	3.40	4.89	.69		6±2	40± 10
				.0050	2.76	2.13	3.39	2.76	.47		15±3	50± 10
C2930	do	9–17	.20	0	7.60	6.92	7.31	7.28	1.22	.0044	.....	.....
				.0025	5.66	5.95	4.15	5.25	.80		7±2	40± 10
				.0050	2.81	3.93	2.58	3.11	.41		15±3	40± 10

EXPERIMENT 12 (JAN 31–MAR. 11)

.....	Quartz sand only	.....	0.20	0	3.50	2.93	3.45	3.29	0.60	0.0013	.....	.....
				.0013	1.30	1.67	1.79	1.59	.41		15± 5	370± 40
				.0026	.70	.65	.69	.68	.21		50±10	620±120
C3175	Russell silt loam	2– 8	.25	0	3.40	4.33	3.62	3.78	.79	.0050	.....	.....
				.0040	2.38	2.12	.....	2.25	.49		12± 5	360±100
				.0080	.82	.75	.65	.74	.24		20±10	630±150
C3177	do	13–23	.25	0	3.94	3.82	3.10	3.62	.70	.0049	.....	.....
				.0040	1.98	1.99	2.57	2.18	.55		12± 3	30± 10
				.0080	.75	.48	.57	.60	.19		50±10	120± 40
C1478	Lebanon silt loam	0– 6	.25	0	4.38	3.54	.....	3.96	.71	.0072	.....	.....
				.0040	3.23	3.68	.....	3.45	.72		10± 3	40± 10
				.0080	2.02	1.18	.....	1.60	.36		20± 5	110± 30
C1479	do	6–11	.25	0	2.33	2.04	2.34	2.24	.52	.0048	.....	.....
				.0040	1.36	1.25	1.30	1.30	.34		15± 5	80± 20
				.0080	.48	.45	.40	.44	.18		60±15	230± 60

TABLE 4.—*Effect of different soil colloids on toxicity of sodium selenite to plant growth in sand-soil mixtures*—Continued

EXPERIMENT 13 (DEC. 9-JAN. 26, PLANTED TO WHEAT)

Soil sample No.	Kind of soil mixed with quartz sand	Depth	P_2O_5 applied per pot	Sodium selenite added per pot (expressed as Se)	Air-dry yield per pot of plants above ground				Average air-dry yield of roots per pot	Se per pot required to reduce yield of plants above ground by one-half	Se in air-dry plants and limit of error of determination	
					Series A	Series B	Series C	Average			Tops	Roots
		Inches	*Gram*	*Gram*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Gram*	*P. p. m.*	*P. p. m.*
.....	Quartz sand only.....	.....	0.20	0	2.00	2.12	1.61	1.91	0.39	0.0031	160± 30	580± 60
				.0020	1.30	1.31	1.08	1.23	.34		450± 50	660±100
				.0040	.73	.76	.74	.74	.28			
B407	Muskingum silt loam.....	0- 7	.20	0	2.12	1.87	1.85	1.95	.39	.0150	80± 20	300±100
				.0060	1.57	1.92	1.61	1.70	.34		140± 30	540±100
				.0120	1.15	1.21	1.31	1.22	.31			
6842	Colby silty clay loam.....	2-10	.20	0	1.93	1.95	2.04	1.97	.38	.0076	130± 20	600±100
				.0060	1.39	1.37	1.10	1.29	.33		700±100	1500±300
				.0120	.21	.21	.31	.24	.11			
9475	Nacogdoches fine sandy loam.....	0- 8	.40	0	2.19	2.15	1.88	2.07	.40	.0226	25± 5	330±100
				.0100	1.88	2.07	2.15	2.03	.40		110± 30	500±100
				.0200	1.27	1.37	1.11	1.25	.33			

EXPERIMENT 14 (FEB. 16–MAR. 23)

.....	Quartz sand only	.....	0.20	0	2.75	2.96	2.70	2.80	0.64	0.0012	.....	.....
				.0013	1.36	1.20	1.23	1.26	.37		40± 5	250± 50
				.0026	.61	.62	.51	.58	.20		35± 5	500±100
300	Chester loam (50 gm. colloid)	0–8	.30	0	4.35	5.15	4.68	4.73	.90	.0077	.....	.....
				.0050	3.62	3.05	2.64	3.10	.65		8± 1	20± 5
				.0150	.17	.59	.37	.38	.12		35± 10	800±150
300	Chester loam (20 gm. colloid)	0–8	.24	0	4.95	4.95	4.90	4.93	.97	.0011	.....	.....
				.0020	.46	.35	.84	.55	.14		6± 3	70± 20
				.0060	.02	.06	.06	.05	.04		.....	80± 40
6678	Kirvin fine sandy loam (60 gm. colloid)	0–12	.40	0	4.49	4.08	3.50	4.02	.66	.0168	.....	.....
				.0120	2.92	2.79	2.11	2.61	.41		10± 2	150± 30
				.0240	1.25	1.13	.83	1.07	.21		18± 6	300± 80
6678	Kirvin fine sandy loam (20 gm. colloid)	0–12	.28	0	2.60	3.24	3.48	3.11	.52	.0096	.....	.....
				.0040	3.37	2.78	2.48	2.88	.52		6± 2	160± 30
				.0080	1.50	2.12	2.24	1.95	.39		35± 10	50± 10
9805	Columbiana clay (75 gm. colloid)	10–25	.50	0	3.60	3.93	3.92	3.82	.85	.0084	.....	.....
				.0150	.44	.43	.38	.42	.15		200± 40	750±100
				.0300	.02	.03	.03	.03	.....		400±100	.....
6842	Colby silty clay loam [1] (50 gm. colloid)	2–10	.20	0	2.10	1.68	2.83	2.20	.....	.0035	.....	.....
				.0030	1.28	1.15	1.35	1.23	.....		20± 4	.....
				.0060	.29	.52	.30	.37	.....		45± 5	.....
6842	Colby silty clay loam [1] (150 gm. colloid)	2–10	.20	0	1.90	1.78	2.12	1.93	.....	.0055	.....	.....
				.0040	.84	1.40	1.43	1.22	.....		10± 2	.....

[1] Plants affected with root rot.

TABLE 5.—*Specific effects of soil colloids on selenite toxicity as related to chemical composition*

Soil sample No.	Kind of soil	Depth	Effect of 50 gm. soil colloid on half-toxicity value (expressed as Se per pot)	Percentage of iron (Fe_2O_3) in colloidal material [1]	Molecular ratio of SiO_2 to $Al_2O_3+Fe_2O_3$ in colloidal material [2]
		Inches	*Gram*	*Percent*	
392	Hagerstown loam	8–30	0.0014	11.31	1.89
C2929	Barnes loam	0– 9	.0020	9.96	3.05
C2930	do	9–17	.0022	10.93	3.00
C805	Hagerstown silt loam	12–33	.0023	9.62	2.03
6842	Colby silty clay loam	2–10	.0024	7.10	3.41
C800	Hagerstown silty clay loam	8–14	.0025	10.80	1.86
8736	Marshall silt loam	0–13	.0026	9.10	2.91
305	Stockton clay adobe	0–38	.0026	10.57	2.87
195	Clarksville silt loam	0–10	.0028	10.05	2.18
6719	Vernon fine sandy loam	0–10	.0031	10.70	2.50
C804	Hagerstown silt loam	3–12	.0033	9.50	2.10
B1086	Spearfish silt loam	0–12	.0034	6.40	2.84
C1479	Lebanon silt loam	6–11	.0035	9.60	2.56
9805	Columbiana clay	10–25	.0035	16.15	.81
188	Orangeburg fine sandy loam	10–36	.0036	10.08	1.71
C3177	Russell silt loam	13–23	.0036	12.41	2.36
C3175	do	2– 8	.0037	11.00	2.43
9804	Columbiana clay	0–10	.0037	15.36	.81
C2918	Carrington loam	13–22	.0038	10.07	2.38
C2917	do	3–13	.0042	10.09	2.39
198	Sassafras silt loam	8–22	.0044	12.73	1.89
B407	Muskingum silt loam	0– 7	.0047	9.97	2.26
C1672	Chester loam	10–34	.0050	17.56	1.74
6379	Kirvin fine sandy loam	12–24	.0051	14.37	1.74
C799	Hagerstown silty clay loam	2– 8	.0051	11.52	1.70
C813	Manor loam	1– 8	.0053	10.33	1.81
C1673	Chester loam	34–60	.0053	20.21	1.53
C1478	Lebanon silt loam	0– 6	.0059	8.80	2.74
6977	Cecil sandy clay loam	0– 6	.0064	14.57	1.34
300	Chester loam	0– 8	.0065	15.93	1.54
9475	Nacogdoches fine sandy loam	0– 8	.0093	28.05	1.07
6678	Kirvin fine sandy loam	0–12	.0170	14.74	2.02

[1] Coefficient of correlation of selenium values with percentage of iron (Fe_2O_3), +0.51

[2] Coefficient of correlation of selenium values with molecular ratio, $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$, −0.32

The accuracy of the half-toxicity values shown in table 5 cannot be calculated exactly, but probably most values are accurate within 10 to 20 percent of the values given. This is indicated by the agreement of duplicate determinations appearing in tables 3, 4, and 7. The duplicate half-toxicity values of the soil colloids are as follows: Colby, 0.0025 and 0.0023; Marshall, 0.0023 and 0.0029; Cecil, 0.0077 and 0.0050; and the Kirvin 12- to 24-inch layer, 0.0050 and 0.0051. There are also 14 determinations of selenite toxicity in pure quartz sand. These are not strictly duplicate determinations, since different shipments of sand varied in the impurities present, but they give some idea of the experimental error. The extremes of the 14 determinations are 0.0010 and 0.0022; the average value is 0.0014, and the standard deviation ±0.0003.

The values given in table 5 show that the soil colloids vary widely in their effect on sodium selenite. The highest value is more than 10 times the lowest. This is in strong contrast with the uniform absence of any effect on sodium selenate. However, in previous work a somewhat greater variation was found in the effect of different colloids on calcium arsenate (*6*).

The values given in table 5 should fairly represent the comparative effects of the different soil colloids on selenite, since they were obtained

by measuring the effects of equal quantities of material under similar conditions. It seems, however, that these values representing the effect of 1 percent of colloid cannot safely be used for calculating the effects of the whole soils on selenite. When the values are multiplied by the percentage of colloid in the soil, the results in some instances are quite far from the actual effect of the whole soils. This is indicated by the results of experiment 14 (table 4) in which the effects of increasing quantities of colloid are compared.

It will be seen that the effect of the colloid on selenite increases with the quantity of colloid applied, but the results are not consistent. In the case of the Colby and Kirvin soil-sand mixtures, increasing the colloid by three times increases the effect on selenite not by three times but by approximately two times. The result with 20 gm. of Chester colloid is anomalous but apparently is not due to experimental error. In previous work with calcium arsenate the effect of the colloid increased in direct proportion to the quantity applied, up to applications of 100 or 150 gm. of colloid, although it was presumed that the relation would not hold for much larger quantities of colloid. The poorer results obtained with selenite might be due to the fact that sodium selenite was applied in solution to the top of the pot; whereas the calcium arsenate was mixed with the whole volume of the sand-soil mixture.

The specific effects of the colloids bear little relation to the broad groups of soils established by soil classification. Some of the data, such as the comparative effects of topsoil and subsoil colloids, indicate that the effect of a colloid may be associated with a minor characteristic. Values given in table 5 for two layers of the same soil are brought together in table 6.

TABLE 6.—*Effects of colloids in two different layers of the same soil type on half-toxicity values*

Kind of soil	Depth of soil sample		Effect of soil colloid on half-toxicity value (expressed as Se per pot)	
	Upper	Lower	Upper	Lower
	Inches	*Inches*	*Gram*	*Gram*
Barnes, Nos. C2929 and C2930	0- 9	9-17	0.0020	0.0022
Carrington, Nos. C2917 and C2918	3-13	13-22	.0042	.0038
Chester, Nos. C1672 and C1673	10-34	34-60	.0050	.0053
Columbiana, Nos. C9804 and C9805	0-10	10-25	.0037	.0035
Hagerstown, Nos. C799 and C800	2- 8	8-14	.0051	.0025
Hagerstown, Nos. C804 and C805	3-12	12-33	.0033	.0023
Kirvin, Nos. 6678 and 6679	0-12	12-24	.0170	.0051
Lebanon, Nos. C1478 and C1479	0- 6	6-11	.0059	.0035
Russell, Nos. C3175 and C3177	2- 8	13-23	.0037	.0036

In five soils the colloidal material of the deeper soil layer had almost exactly the same effect on selenite toxicity as the colloid in the layer nearer the surface, but in four other soils the upper soil colloid was considerably more effective than the lower. It was thought possible that the greater effectiveness of the upper colloid obtaining in some cases might be due to organic matter. Several experiments were conducted to see if this was correct.

TABLE 7.—*Effects of organic matter, water content, and iron gels on toxicity of sodium selenite* [1]

EXPERIMENT 15 (NOV. 12–DEC. 21)

Soil or material added to quartz sand	Water content of pot	P_2O_5 applied per pot	Sodium selenite per pot (expressed as Se)	Air-dry yield per pot of plants above ground				Average air-dry yield of roots per pot	Se per pot required to reduce yield of plants above ground by one-half	Se in air-dry plants and limit of error of determination	
				Series A	Series B	Series C	Average			Tops	Roots
	Percent	*Gram*	*Gram*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Gram*	*P. p. m.*	*P. p. m.*
Quartz sand only	0.20		0	1.98	1.93	2.00	1.97	0.35	0.0012	90±20	450±100
			.0013	.65	1.05	1.00	.90	.19			
Peat	.20		0	2.30	2.48		2.39	.36	.0027	9± 3	210± 50
			.0013	1.84	1.78		1.81	.28			
Peat and $CaCO_3$	.20		0	2.43	3.13		2.78	.42	.0018	40±10	150± 40
			.0013	1.73	1.82		1.78	.27			
Activated charcoal	.20		0	2.37	2.55		2.46	.40	.0018	60±10	240± 80
			.0013	1.65	1.53		1.59	.31			
Humus	.20		0	2.40	2.68		2.54	.39	.0023	20± 5	170± 30
			.0013	1.70	1.95		1.83	.30			
Kirvin soil, No. 6679 only	.40		0	1.77	1.08	1.38	1.41	.20	.0063	100±20	640±130
			.0070	.56	.67	.68	.64	.13			
Kirvin soil, No. 6679+peat	.40		0	2.84	3.59		3.22	.47	.0058	20± 5	70± 20
			.0070	1.24	1.27		1.26	.21			
Kirvin soil, No. 6679+peat+$CaCO_3$	.40		0	3.11	3.24		3.18	.38	.0058	30± 5	90± 30
			.0070	1.17	1.36		1.27	.19			
Kirvin soil, No. 6679+activated charcoal	.40		0	2.43	2.37		2.40	.32	.0045	90±20	560±100
			.0070	.40	.70		.55	.16			
Kirvin soil, No. 6679+humus	.40		0	1.54	1.30		1.42	.23	.0085	90±20	580±100
			.0070	.78	.90		.84	.16			

RICE GROWN INSTEAD OF MILLET. EXPERIMENT 16 (FEB. 21–APR. 4)

Quartz sand only	15	0.20	0	4.02	3.68	4.09	3.93	1.50	0.0015	70±10	150±30
			.0015	1.76	1.92	2.35	2.01	.46		90±20	680±80
			.0030	.75	.97	.90	.87	.40			
	29	.20	0	5.47	5.81	5.05	5.44	2.14	.0025	25± 5	130±30
			.0015	3.27	4.06	4.25	3.86	1.24		130±20	350±50
			.0030	1.89	2.28	2.55	2.24	.75			
Muskingum soil, No. B407	15	.20	0	5.45	4.87	5.38	5.23	1.79	.0079	25± 5	120±30
			.0050	4.20	3.88	4.10	4.06	1.15		50±10	120±20
			.0100	1.60	1.22	2.16	1.66	.50			
	29	.20	0	5.43	5.98	5.56	5.66	2.10	.0083	15± 3	35±10
			.0050	4.27	4.95	4.05	4.42	1.44		40±10	140±30
			.0100	1.16	2.98	1.99	2.04	.58			
Hyperhumus	15	.20	0	4.37	4.62	3.80	4.26	1.65	.0019	100±20	30± 5
			.0020	1.92	1.72	2.25	1.96	.62		80±20	180±40
			.0040	.57	.72	.88	.72	.28			
	29	.20	0	4.97	5.01	5.25	5.08	1.79	.0028	40±10	100±20
			.0020	2.85	3.07	2.52	2.81	.85		60±10	
			.0040	1.90	2.40	2.06	2.12	.68			
Muskingum soil, No. B407+Hyperhumus	15	.20	0	5.77	5.96	5.07	5.60	1.93	.0087	12± 3	60±20
			.0050	4.06	4.32	4.31	4.23	1.12		20± 5	90±20
			.0100	2.78	1.31	2.79	2.29	.59			
	29	.20	0	5.32	5.75	5.39	5.49	1.74	.0085	15± 3	260±30
			.0050	4.52	4.36	4.18	4.35	1.29		40±10	70±15
			.0100	2.15	2.77	1.19	2.04	.57			

EXPERIMENT 17 (MAR. 1–APR. 4)

Quartz sand only		0.20	0	3.52	2.80	3.68	3.33	0.76	0.0010	60±15	400±80
			.0013	1.00	.96	1.22	1.06	.40			
Iron gel, dried		.50	0	6.22				1.40			
			.0100	2.32				.80	.0080	30± 5	600±150
			.0200	.47				.21		60±10	950±250
			.0300	.07				.02		140±70	500±250

EXPERIMENT 18 (DEC. 27–FEB. 10)

Quartz sand only		0.20	0	1.34	1.50	1.65	1.50	0.27			
			.0015	.65	.80	.98	.81	.19	0.0017	40±10	430± 80
			.0030	.27	.36	.34	.32	.10		150±20	1,100±200
			0	1.30				.23			
			.0060	1.03				.22			15±10
			.0120	.54				.14			7± 7
Iron gel, moist		.50	.0240	1.35				.26	.1094	10± 5	200±100
			.0480	.70				.17		30±15	120± 60
			.0960	.80				.23		70±15	430± 80
			.1920	.14				.06		200±70	1,300±400

[1] Soils added at rate of 50 gm. per pot, organic materials and iron gels at rate of 10 gm. per pot. Millet grown except as otherwise indicated.

EXPERIMENTS TO EXPLAIN SPECIFIC EFFECTS OF DIFFERENT SOIL COLLOIDS

In experiment 15 (table 7), various organic materials were applied in conjunction with the Kirvin 12- to 24-inch material to see if the two materials together would have an effect approaching that of the Kirvin surface layer. The Kirvin subsoil was added to quartz sand at a rate to supply 50 gm. of colloid per pot; the organic materials were added at the rate of 10 gm. per pot. The peat was a reed peat of pH 4.84; the "peat+$CaCO_3$" was the same peat limed to pH 6.81. The activated charcoal was a commercial product rendered practically neutral by washing with distilled water. The so-called humus was the finest, more decomposed forest litter found on top of Chester soil. It had a pH value of 3.89. Millet was the crop plant.

The organic materials alone, that is, mixed with quartz sand, all had slight capacities for reducing the toxicity of sodium selenite. Added to the mixture of sand and Kirvin soil, only the humus increased the capacity of the mixture for rendering selenite nontoxic, but the half-toxicity value characteristic of the whole mixture (sand+Kirvin soil+humus) was not significantly greater than that of the separate constituents. The results of this experiment do not support the idea that the toxicity values of some A horizons are higher than those of B horizons owing to the presence of more organic matter.

It was thought possible, however, that some kind of organic matter might affect toxicity values by creating reducing conditions. An experiment was conducted in which exaggerated reducing conditions were produced by maintaining an excessive water content in the sand-soil mixtures and by maintaining an excessive water content in conjunction with added organic matter. Robinson (*14*) has shown that when soils are kept under submerged conditions considerable iron is rendered soluble, particularly in the case of soils high in organic matter. If soluble iron were produced in the sand-soil mixture, this might combine with the selenite and render it less toxic.

Experiment 16, in which excess water was kept in some of the pots, was conducted with rice, since this plant grows well in soil with either a normal or excessive water content. In this experiment the standard fertilizer shown on page 559 was applied; 7 rice plants were grown per pot; 10 gm. of Hyperhumus was applied per pot, and the Muskingum soil was applied at the rate of 50 gm. of colloid per pot. The Hyperhumus is a commercial peat of pH 5, used currently for soil improvement. All pots were kept at a water content of 15 percent until the plants formed their third leaf. The water content of half the pots was then raised to 29 percent, which was sufficient to more than saturate the sand and the sand-soil mixtures. The results of experiment 16 are shown in table 7.

The sodium selenite was somewhat less toxic in quartz sand at the higher water content than at the lower; that is, the half-toxicity value of the sand was greater at the high water content. Whether the capacities of the soil and peat for reducing selenite toxicity were affected by the water content can be seen when the half-toxicity values of quartz sand are subtracted from those of the sand-soil mixtures. Under low and high water content the Muskingum soil had half-toxicity values of 0.0064 gm. and 0.0058 gm., the Hyperhumus had half-toxicity values of 0.0004 gm. and 0.0003 gm., and the mixture of Muskingum soil and Hyperhumus had half-toxicity values of 0.0072

gm. and 0.0060 gm. It is also to be noted that the half-toxicity values of the mixture of Muskingum soil and Hyperhumus are almost exactly the sum of the half-toxicity values of the separate constituents. Evidently reducing conditions induced by saturation of the sand-soil mixtures had no effect on the capacity of Muskingum soil colloids for rendering sodium selenite less toxic, even when considerable organic matter was present.

Before experiment 16 (table 7) was carried out, a similar experiment had been conducted with a moss peat of pH 5 instead of Hyperhumus. Seed was planted on January 2, but growth was so weak and spindling, presumably owing to insufficient sunlight, that the plants were cut on January 25. The air-dry yields of pots receiving no selenium were only about 0.10 gm. per pot. It was assumed that this experiment was a complete failure; hence seed for experiment 16 (table 7) was planted on February 21. It is of interest to note that the slight yields of this seemingly abortive experiment gave half-toxicity values similar to those of experiment 16 just discussed. Under low and high water content the half-toxicity values were as follows: For quartz sand 0.0015 and 0.0019 gm.; for the Muskingum soil, 0.0075 and 0.0071 gm.; for the peat, 0.0005 and 0.0021 gm.; and for the mixture of peat and Muskingum soil, 0.0070 and 0.0081 gm.

Naturally it was thought that the effect of the colloidal materials on selenite was at least partly due to the iron content, since work of Williams and Byers (*16*) had indicated that soils may contain an insoluble basic ferric selenite. Experiments were therefore conducted with artificial iron gels; not that positive results would necessarily prove the correctness of the idea, but that negative results would practically disprove it. The results of experiments 17 and 18 with a dry and a moist iron gel are shown in table 7. The gels were prepared from ferric chloride and sodium hydroxide. The precipitates were washed by decantation until they began to disperse. The moist gel was then dried on a steam bath. About 10 gm. of the dry gel and a quantity of moist gel equivalent to the 10 gm. of dry gel were applied per pot. It was necessary to apply a large amount of phosphate to the pots receiving iron gels in order to supply the plants with phosphoric acid. The results of experiment 18 indicate that the quantity of phosphate applied to pots containing the moist gel was insufficient. The variable yields with selenite applications less than 0.0960 gm. of selenium per pot were presumably due to variations in available phosphate. It was difficult to mix the phosphate evenly with the moist mixture of sand and iron gel. The value of about 0.1 gm. of selenium required for reducing the yield one-half in the presence of the moist gel is probably only approximate, but it is evidently many times greater than the 0.0070 value characterizing the dry gel. The effect of iron gels on sodium selenite obviously varies greatly with the condition of the gel and may be very considerable.

SPECIFIC EFFECTS OF SOIL COLLOIDS AS RELATED TO THEIR CHEMICAL COMPOSITION

The figures shown in column 4 of table 5 are strictly the results of the soil applications but are assumed to represent the effects of the 50 gm. of colloidal material present. Presumably the values are specific values for the soil colloids and may be regarded as showing

that the selenite, expressed as grams of selenium per pot, was rendered unavailable or nontoxic by 50 gm. of colloid. These values are significantly but imperfectly related to the ultimate chemical composition of the soil colloids. As shown at the bottom of table 5, the effects of the colloids on selenite are more closely related to the percentages of iron present than to the silica-sesquioxide ratios of the colloids. The molecular ratios of iron to silica plus alumina were calculated and found to be related to the selenite values in about the same degree as the simple percentages of iron. The coefficient of correlation was +0.44.

These results are similar to those obtained in a previous study dealing with the effects of soil colloids on the toxicity of calcium arsenate (*6*). The coefficient of correlation between the arsenate values and percentages of iron was +0.59, the same, within limits of error, as the correlation between selenite and iron. It would seem that the arsenate and selenite values should be quite closely correlated, but apparently they are not. Twelve of the soils tested in this study of sodium selenite were used in the work on calcium arsenate. The effects of these soils on selenite toxicity are related to the effects on arsenate toxicity only to the degree expressed by the coefficient 0.47.

The fact that toxicity values of sodium selenite are not more closely related to the percentages of iron than by coefficient 0.51 may be explained on the ground that it is reactive iron rather than total iron which is effective in rendering the selenite nontoxic. Unfortunately, methods are not available for determining the reactivity of iron in the soil colloids. But presumably the soil colloids may contain iron in forms that vary widely in their reactivity with selenite, just as did the moist and dried iron gels previously mentioned. It is known that a varying proportion of the iron is present as silicate and that the free iron oxide varies in crystalline structure and degree of hydration. Possibly each colloid contains not simple reactive and nonreactive iron but iron in various degrees of reactivity, just as artificial catalysts contain atoms of varying reactivity. Such a condition could account for the significant, but not close, correlation between the specific effects of the colloids on arsenate and selenite.

Another factor affecting the toxicity values may be microbiological activity. There was no control of this in the experiments reported. According to Maassen (*11*) there are several micro-organisms capable of reducing selenium salts to volatile organic compounds; presumably sodium selenite could be reduced to metallic selenium in the soil, since Hurd-Karrer has reported the presence of metallic selenium in wheat roots (*10*). Hurd-Karrer (*9*) found elementary selenium nontoxic. The toxicities of volatile selenium compounds in the soil have not been determined, but presumably they are different from that of sodium selenite. The formation of such compounds, therefore, would probably affect the toxicity values.

The fact that during an experiment there was usually a characteristic selenium odor in the greenhouse indicates that there was some microbiological action on the selenite applied. But whether it was of such a character or magnitude as to affect the half-toxicity values appreciably is uncertain. Evidently it was not the chief factor affecting the values. If it had been, the correlation between the iron content of the colloids and their effects on selenite would hardly have been as high as +0.51.

SELENIUM ABSORBED BY THE PLANTS

The quantities of selenium absorbed by the plants were determined by separate analyses made of the roots and tops by the method described by Williams and Lakin (*17*). The limits of accuracy of the selenium determinations are shown by the figures following the ± sign. A value of 40±5 p. p. m. indicates that the plant substance contained at least 35 p. p. m. of selenium and not more than 45 p. p. m. Large values for the limit of error are due to the small quantities of plant substance available for analysis. Because of the large allowance that must be made for the limits of analytical error in many instances, conclusions cannot be drawn regarding the comparative selenium content of many individual samples. But conclusions based on average figures of several samples should be reliable. The following generalizations can be made with considerable certainty.

When plants are grown with selenium applied as sodium selenite the roots contain a much higher percentage of selenium than the tops. There are no exceptions to this generalization in the millet experiments. The percentage of selenium in millet roots averages 8.6 times the percentage in the tops for 107 samples grown in experiments reported here. For 23 samples of rice the percentage of selenium in the roots averages 3.9 times that in the tops, and in 14 samples of wheat the average figure for the roots is 3.1 times that for the tops. The wide variations in the relative amounts of selenium in the roots and tops in different samples indicate that no fixed proportion should be expected in the percentages in the 2 parts of the plant.

With selenium applied as sodium selenate the opposite condition obtains; the concentration of selenium in the tops exceeds that in the roots. This was not established in the writers' previous experiments with millet, since only the tops were analyzed. Hurd-Karrer (*10*), however, has shown that it holds for wheat, and the writers have found that it holds for radishes. In an experiment with the Manor soil, in which four lots of radishes were grown with additions of sodium selenate, the selenium content of the radish roots ranged from 350 to 690 p. p. m., while the tops contained from 760 to 1,800 p. p. m.

The concentration of selenium in the whole plant (the weighted average of the percentages of selenium in roots and tops) tends to increase in direct proportion to the quantity of sodium selenite applied. This is apparent on comparing the selenium content of plants growing with single and double applications of sodium selenite. Thirty-four such comparisons for millet can be made from data given in tables 4 and 7. The plants grown with the double applications of sodium selenite contain on an average 2.7 times as much selenium as plants grown with the single applications. Many individual cases vary widely from this relation, as shown by the fact that the figure 2.7 is subject to a standard deviation of ± 1.2.

If it is assumed that selenium in the plant varies directly with the quantity of selenium applied, the selenium content of plants at half injury can be calculated from the data given in tables 4 and 7. When this is done it appears that plants grown in the sand-soil mixtures usually contain a smaller concentration of selenium at half injury than plants grown in quartz sand. This conclusion is based on 32 comparisons for millet and 6 for rice; the only exceptions to the

generalization are 6 of the comparisons for millet. The average figure for the 32 millet comparisons is only 0.72 as much selenium in the plants grown in sand-soil mixtures as in plants grown in pure sand. The average figure for the 6 comparisons involving rice is only 0.48 as much selenium in the plants grown in sand-soil mixtures. This difference in the selenium content of plants grown in sand-soil mixtures and in pure sand is probably connected with the different growth conditions in the 2 mediums, but it is not evident what the determining condition is. The fact that the selenium content of plants grown in sand-soil mixtures is less than that of sand-grown plants at the same degree of injury indicates that the soil application affects the toxicity of selenium within the plant.

COMPARATIVE EFFECTS OF SODIUM SELENITE ON WHEAT, RICE, AND MILLET

The comparative effects of sodium selenite on wheat, rice, and millet may be judged from figures given in previous tables for the quantities of selenite required to produce half injury. These figures are brought together in table 8. The half-toxicity value for millet in quartz sand is the average of 14 determinations, and the value for wheat in quartz sand is the average of 2 almost identical determinations shown in table 2 and in table 4, experiment 13.

In pure quartz sand, sodium selenite is equally toxic for rice and millet but only half as toxic for wheat; that is, it requires twice as much selenite to reduce the yield of wheat one-half as it does to reduce the yield of millet one-half. A similar difference between millet and wheat was found in previous work with sodium selenate (7). The growth of millet in quartz sand was reduced one-half by 0.0044 gm. of selenium as selenate per pot, whereas 0.0072 gm. of selenium was required to produce the same effect on wheat (7). Apparently the concentration of selenite or selenate required to injure wheat is greater than that required to injure millet, not because wheat is more resistant to absorption of the ions but because it is less injured by the ions after they are absorbed. This is shown by the analytical data; the wheat plants are considerably higher in selenium than the millet plants.

TABLE 8.—*Effects of quartz sand and soil colloids on sodium selenite required for half injury of millet, rice, and wheat*

Material affecting selenite toxicity	Effect of material on selenium per pot required to produce half injury in—		
	Millet	Rice	Wheat
	Gram	*Gram*	*Gram*
Quartz sand only	0.0014	0.0015	0.0032
50 gm. Muskingum soil colloid	.0047	.0064	.0119
50 gm. Colby soil colloid	.0024	----------	.0045
50 gm. Nacogdoches soil colloid	.0093	----------	.0195

It s significant that the values representing the effects of the soil colloids on selenite toxicity are twice as great when measured by wheat as when measured by millet. As previously mentioned, the effect of

the soil is obtained by subtracting the quantity of selenium required for half injury in the sand from the selenium required for half injury in the sand-soil mixtures. The blank for the sand is twice as great for wheat as for millet; but if the colloidal material combined with the selenite to form a complex wholly unavailable to plants, the value representing the effect of the colloid on the selenite required for half injury should be no more for wheat than for millet. However, if the selenite-colloid combination is slightly available to plants, the effect of the colloid on sodium selenite might be expected to be twice as large when measured by wheat as when measured by millet. As compared with millet, wheat would require twice as much of the slightly available compound for half injury, just as it required twice as much of the wholly available selenite in quartz sand.

DIFFERENCE BETWEEN THE EFFECTS OF SODIUM SELENITE AND SODIUM SELENATE

In the two experiments with wheat shown in tables 2 and 4, the plants injured by selenite were normal in appearance although they tended to wilt more readily than normal plants. In the previous work with sodium selenate the ivory-white chlorosis considered typical of selenium injury was very pronounced in wheat. This difference in the appearance of wheat grown with selenate and with selenite has been pointed out by Hurd-Karrer (*10*). Millet, when grown with selenate applications sufficient to curtail growth markedly, showed at times some yellowing of the leaves, but when grown with similar selenite applications the plants were a normal green.

Other differences in the behavior of sodium selenite and selenate have already been mentioned. All the differences observed are summarized in table 9.

TABLE 9.—*Difference between selenates and selenites*

Respect in which selenate and selenite differ	Selenate	Selenite
How sulfates affect toxicity	Diminish	No effect.
How soil colloids affect toxicity	Practically no effect	Diminish.
Se absorbed, predominately in	Tops	Roots.
Symptom produced in wheat	Chlorosis	None.[1]

[1] Except where the sulfate supply is insufficient for normal growth.

The fact that soil colloids have a marked effect on the toxicity of sodium selenite but practically no effect on the toxicity of sodium selenate may explain observations made in the survey of seleniferous areas. Many plant and soil analyses show that there is little correlation between the total selenium in the soil and the selenium content of the vegetative cover. This might be expected if selenium occurs in soils as both selenate and selenite. The selenate selenium should be highly available in all soils; it should be practically unaffected by soil colloids; and its absorption should vary somewhat with the sulfate content. On the other hand, selenium present as selenite should be only slightly available; its availability should be unaffected by sulfate, but the availability should vary with the kind and quantity of colloidal material present.

SUMMARY

This investigation deals with the effects of soil colloids on the toxicity of sodium selenite to millet as determined by vegetative experiments in quartz sand and sand-soil mixtures. Thirty-two soil samples representative of 22 soil types were tested.

The toxicity of sodium selenite, unlike that of sodium selenate, is not affected by the sulfate supply. It is also independent of the phosphate supply as long as this is sufficient for maximum growth.

The specific effects of different soil colloids on selenite toxicity vary more than tenfold. Their effects bear little relation to the great soil groups. Colloids in two different layers of the same soil have almost identical effects on selenite in some cases, and in other cases the surface-layer colloid has a greater effect than the colloid in the lower layer.

Experiments with several peats failed to show an influence of organic matter on the capacity of the colloid for reducing selenite toxicity, even under conditions of a supersaturated water content. Artificial iron gels had a high capacity for reducing selenite toxicity. A moist gel had a much greater capacity than a dried gel.

The total iron content of soil colloids is correlated with effects of the colloids on selenite toxicity to the degree shown by the coefficient ± 0.51. It is suggested that lack of a closer correlation is due to varying reactivities of the iron content.

Plants supplied with sodium selenite contain a higher percentage of selenium in the roots than in the tops. The reverse condition obtains for plants supplied with sodium selenate. Plants grown in quartz sand contain a higher percentage of selenium at half injury than plants grown in sand-soil mixtures.

Rice and millet require about the same concentrations of serenite for half injury; wheat requires about twice as much in both quartz sand and sand-soil mixtures. The fact that the same difference between wheat and millet holds for sand-soil mixtures as for quartz sand suggests that the combination of soil colloid with selenite is slightly available rather than wholly unavailable.

Differences between the effects of selenates and selenites are pointed out.

LITERATURE CITED

(1) Alexander, Lyle T., Byers, Horace G., and Edgington, Glen.
1939. A chemical study of some soils derived from limestone. U. S. Dept. Agr. Tech. Bul. 678, 27 pp.

(2) Brown, Irvin C., and Byers, Horace G.
1935. The chemical and physical properties of dry-land soils and of their colloids. U. S. Dept. Agr. Tech. Bul. 502, 56 pp.

(3) ——— and Byers, Horace G.
1938. Chemical and physical properties of certain soils developed from granitic materials in New England and the Piedmont, and of their colloids. U. S. Dept. Agr. Tech. Bul. 609, 56 pp.

(4) Byers, Horace G., Alexander, Lyle T., and Holmes, R. S.
1935. The composition and constitution of the colloids of certain of the great groups of soils. U. S. Dept. Agr. Tech. Bul. 484, 39 pp.

(5) Gile, Philip L.
1933. The effect of different colloidal soil materials on the efficiency of superphosphate. U. S. Dept. Agr. Tech. Bul. 371, 50 pp., illus.

(6) ———
1936. The effect of different colloidal soil materials on the toxicity of calcium arsenate to millet. Jour. Agr. Res. 52: 477–491, illus.

(7) GILE, PHILIP L., LAKIN, HUBERT W., and BYERS, HORACE G.
1938. EFFECT OF DIFFERENT SOIL COLLOIDS AND WHOLE SOILS ON THE TOXICITY OF SODIUM SELENATE TO MILLET. Jour Agr. Res. 57: 1–20, illus.

(8) ——— MIDDLETON, H. E., ROBINSON, W. O., FRY, W. H., and ANDERSON, M. S.
1924. ESTIMATION OF COLLOIDAL MATERIAL IN SOILS BY ADSORPTION. U. S. Dept. Agr. Bul. 1193, 42 pp.

(9) HURD-KARRER, ANNIE M.
1935. FACTORS AFFECTING THE ABSORPTION OF SELENIUM FROM SOILS BY PLANTS. Jour. Agr. Res. 50: 413–427, illus.

(10) ———
1937. COMPARATIVE TOXICITY OF SELENATES AND SELENITES TO WHEAT. Amer. Jour. Bot. 24: 720–728, illus.

(11) MAASSEN, ALBERT.
1902. DIE BIOLOGISCHE METHODE GOSIO'S ZUM NACHWEIS DES ARSENS UND DIE BILDUNG ORGANISCHER ARSEN–, SELEN- UND TELLURVERBINDUNGEN DURCH SCHIMMELPILZE UND BAKTERIEN. [Germany] K. Gsndhtsamt. Arb. 18: [475]–489.

(12) MIDDLETON, H. E., SLATER, C. S., and BYERS, HORACE G.
1932. PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE SOILS FROM THE EROSION EXPERIMENT STATIONS. U. S. Dept. Agr. Tech. Bul. 316, 51 pp.

(13) ——— SLATER, C. S., and BYERS, H. G.
1934. THE PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE SOILS FROM THE EROSION EXPERIMENT STATIONS—SECOND REPORT. U. S. Dept. Agr. Tech. Bul. 430, 63 pp., illus.

(14) ROBINSON, W. O.
1930. SOME CHEMICAL PHASES OF SUBMERGED SOIL CONDITIONS. Soil Sci. 30: 197–217.

(15) ——— and HOLMES, R. S.
1924. THE CHEMICAL COMPOSITION OF SOIL COLLOIDS. U. S. Dept. Agr. Bul. 1311, 42 pp.

(16) WILLIAMS, K. T., and BYERS, H. G.
1936. SELENIUM COMPOUNDS IN SOILS. Indus. and Engin. Chem. 28: 912–914.

(17) ——— and LAKIN H. W.
1935. DETERMINATION OF SELENIUM IN ORGANIC MATTER. Indus. and Eng. Chem., Analyt. Ed. 7: 409–410.

PHYSICAL AND CHEMICAL PROPERTIES OF FLANNELS CONTAINING DIFFERENT PROPORTIONS OF NEW AND REPROCESSED WOOL [1]

By BARBARA BAILEY [2]

Research assistant in home economics, South Dakota Agricultural Experiment Station

INTRODUCTION

Recent efforts to secure "truth in fabrics" legislation, requiring manufacturers to label textiles containing wool with the percentages of new wool present,[3] have led to interest in the quality of fabrics containing new and reprocessed wool in various proportions. South Dakota as a wool-producing State has an interest in variations or differences in the physical and chemical properties of fabrics containing mixtures of new and reprocessed wool. Accordingly in 1938 a study of certain physical and chemical properties of flannel fabrics manufactured from mixtures of new wool and shoddy was initiated. While performance tests of the fabrics have not as yet been conducted, it has been possible to determine the effects of dry cleaning and pressing upon the fabric properties.

Relatively few reports have appeared of investigational work on wool fabrics of known composition. The spinning and weaving qualities of wool from British pedigreed sheep were investigated at the University of Leeds (*7, 8, 9*)[4] and the fiber, yarn, and fabric characteristics determined. Another study of the same type on wool from British breeds of sheep was reported by Barker (*3*) to the New Zealand Government. The Bureau of Animal Industry of the United States Department of Agriculture, in cooperation with the Bureau of Home Economics, has recently published the results of a study of the serviceability of blankets made from four blends of wool (*5*). Wools selected from purebred flocks of Rambouillet and Corriedale sheep and reworked fiber were used in the manufacture of the blankets. The fabrics were given actual service tests, and the rates of chemical and physical deterioration were determined. These Bureaus have in progress further work with blankets involving the use of various grades of reprocessed wool and mohair in comparison with new wool[5] and of suitings made from blends of new wool with reprocessed wool and spun rayon.[6]

[1] Received for publication January 7, 1941. Paper No. 142 from the South Dakota Agricultural Experiment Station.

[2] Grateful acknowledgment is made to Dr. S. P. Swenson, associate agronomist, South Dakota Agricultural Experiment Station, and to Dr. F. R. Immer, professor of agronomy and plant genetics, University of Minnesota, for assistance in the statistical interpretation of the data, and to the Division of Home Economics, University of Minnesota, for the use of their air-conditioned laboratory and textile-testing equipment.

[3] The Wool Products Labeling Act, passed by the 76th Cong., 3d sess., was approved October 14, 1940, and became effective July 14, 1941.

[4] Italic numbers in parentheses refer to Literature Cited, p. 597.

[5] HAYS, MARGARET B., ROGERS, R. E., and HARDY, J. I. NOTES ON GRADUATE STUDIES AND RESEARCH IN HOME ECONOMICS AND HOME ECONOMICS EDUCATION, 1938-39. U. S. Dept. Agr., Off. Expt. Stat., 219 pp. [Mimeographed.] (See p. 121.)

[6] See p. 119 of the reference cited in footnote 4.

MATERIALS

Rambouillet sheep, raised at South Dakota State College, furnished the new wool used in the present experiment. Ten fleeces weighing approximately 10 pounds each were shipped to the Lowell Textile Institute for fabrication. Reprocessed wool of a high quality from pastel sweater clippings was purchased on the market by members of the institute staff and blended with the new wool. The fiber used for the first fabric (No. 100) was made of 100 percent new wool; for the second (No. 75), approximately 75 percent new wool and 25 percent reprocessed wool; for the third (No. 50), approximately 50 percent new wool and 50 percent reprocessed wool; for the fourth (No. 25), approximately 25 percent new wool and 75 percent reprocessed wool. The exact weights of the fibers are recorded in table 1, which shows that considerable machine waste resulted in the course of the manufacturing. Thus, while the fiber blends indicated above were used as the raw materials for each of the fabrics, these percentages may not have been maintained in manufacture. Further evidences of shifts in these percentages will be indicated in the discussion below.

Emulsion consisting of 75 percent water and 25 percent oil (fat and mineral oil) was applied to the stock in picking. All of the lots were spun to 3½ run Z twist and an identical lay-out was used consisting of No. 9 reed, 4 yarns per dent, 1,560 warps, 43½ inches in reed, and 36 fillings, resulting in a 2 × 2 even-twill fabric. After weaving, each fabric was given a simple finishing process consisting of washing and pressing. The finished yardage and weight as reported by Lowell Textile Institute are shown in table 1.

TABLE 1.—*Weights of new and reprocessed wool fiber used in manufacturing the four experimental fabrics, and length, width, and finished weight of the four fabrics*

Fabric No.	Fiber weights used[1]		Finished fabric—			
	New wool	Reprocessed wool	Length	Width	Weight	
	Pounds	*Pounds*	*Yards*	*Inches*	*Pounds*	*Ounces*
100	14.4	0.0	20.6	35.5	9	10
75	10.8	3.5	20.4	36.4	9	6
50	7.2	7.0	20.9	36.0	9	4
25	4.0	----------	18.0	36.5	7	8

[1] Total carding and spinning waste for the 4 fabrics was 16 pounds.

METHODS

PHYSICAL-PROPERTY DETERMINATIONS

Each of the four fabrics manufactured was tested physically and chemically as it was received from the manufacturer and after it had been commercially dry-cleaned and pressed 15, 30, and 45 times. The process used in dry cleaning was described as consisting of running in dry-cleaning solvent (Stoddard solvent) in a regular cylindrical dry-cleaning washer for 10 minutes with paste soap and rinsing for 20 minutes on a filter so constructed as to remove the heavy "soil"

from the solvent. The solvent was passed continuously from the the washer through the filter and returned again to the washer. After each cleaning the fabrics were pressed on a regular steam press.

Throughout this investigation all testing requiring the maintenance of moisture equilibrium in the fabrics was conducted in a conditioning room maintained at a standard atmosphere of 65 percent relative humidity ± 2 percent at 70° F. ± 2, as specified by the American Society for Testing Materials (*2, p. 184*). All samples were conditioned for a minimum of 6 hours before testing. Samples used in determining weight per square yard and yarn number were dried to constant weight at 105° C. Yarn-count and twist determinations were conducted under prevailing atmospheric conditions, as were all fiber studies.

The means and standard deviations of measurements were calculated in all instances possible, and the analysis of variance for significance of difference between means was applied in some cases.

A 1-pound sample of scoured new-wool fiber was taken from various parts of the lot for use in measurements of fiber diameter, contour, length, and crimp, and a similar sample was taken from the reprocessed wool in the oil. Portions of the fiber samples were hand-carded and carefully blended. By means of intestinal forceps, recommended by Townsend (*11*) for sampling fiber for length determinations, repeated draws were made and blended until samples of the correct size for each type of fiber measurement were secured.

A modification of the cross-section method recommended by the American Society for Testing Materials (*2, p. 174*) was used to determine the diameter and contour of the new and reprocessed wool. The device described by Hardy (*1*) was used in preparing the cross-sectional microscopic slides. The cross-section mounts were placed on a microscope stage set at right angles to the base and, by the use of strong artificial light, their images were projected onto a ground-glass plate placed at such a distance from the microscope that each fiber section was magnified approximately 500 times. One thousand fiber sections were measured to an accuracy of one micron, as recommended by the American Society for Testing Materials (*2*), at (1) their greatest diameters and (2) the diameters at right angles to their greatest diameters.

The samples for determination of fiber length were prepared according to the method described by Townsend (*11*). Three groups of 150 fibers each were measured to the nearest 0.25 inch by extending the fiber sufficiently to remove the crimp but not to stretch it.

The number of crimps in each fiber measured for length was counted over the entire length, and the average number of crimps per inch was calculated.

Yarn number in the present study was recorded as the number of thousands of yards per pound (typp system). Prior to the determination three 10-yard lengths were dried to constant weight. In the preparation of the samples an attempt was made to measure lengths of yarn from which the crimp had been removed without stretching the yarn. The resulting values were calculated in typp to 13 percent regain—the standard regain for woolen yarn (*2*)—and the results used in the adjustment of tension in determining yarn twist.

The average number of twists per inch was determined using the new-type Suter precision twist tester with spinning twist attachment. The gage length was 10 inches and 50 yarns per sample were measured.

A Scott single-strand tester with autographic recorder was used in the determination of yarn stength. The clamps were set 10 inches apart and moved at a speed of 12 inches per minute. Tensile strength and elongation of yarns removed from the fabric at scattered points were measured in each instance.

Wherever the nature of the test made such measurements possible, samples of both warp and filling sections of fabric were prepared. With the exception of the method for abrasion, all methods were standard procedures of the American Society for Testing Materials (*2*).

Two-inch squares taken at five scattered positions on each fabric were composited for the determination of fabric weight. All of the results were calculated to 13-percent regain and expressed in ounces per square yard.

Measurements of thickness were made on each of 10 grab tensile-strength samples by means of the Schiefer compressometer with a ⅜-inch foot at a pressure of 3.4 pounds per square inch. The results were recorded in the number of 0.001 inch of thickness.

A Lowinson counter was used for the determination of the number of yarns per inch. The 10 samples of fabric prepared for the determination of strength by the strip method were measured for a distance of 1 inch.

A 10-inch square was marked on each fabric before it was sent to a commercial dry cleaner and was measured on its return. Thus shrinkage is reported in percentage shrinkage after 15, 30, and 45 dry cleanings and pressings.

J-type Scott testers with recording serigraphs were used throughout for the determination of the tensile strength and elongation of the experimental samples. A 150- to 300-pound-capacity machine was used for the grab samples and a 55- to 110-pound-capacity machine for the strip samples. Ten strips of fabric to form the sample were cut 1½ inches wide by 6 inches long and were raveled to 1 inch. Two-inch fabric jaws set 3 inches apart were employed in the strip tests. Ten grab tensile-strength samples per fabric were cut 4 inches wide and 6 inches long. One-inch front and 3-inch back jaws were used for the grab determinations. On both machines the jaws traveled at the rate of 12 inches per minute. Tensile-strength values were recorded in pounds and elongation in inches.

The ball-burst attachment for the Scott tester was used for the determination of bursting strength. Metal balls 1 inch in diameter and 1¾-inch rings were employed. Ten determinations were made on each fabric, and the results were recorded in terms of force in pounds required to thrust the ball through the fabric. Stretch was recorded by means of the serigraph.

The test specimens used in the determination of tearing strength by the tongue method were cut 3 by 8 inches in size. Three-inch longitudinal cuts were made lengthwise of the specimens from the center of one of the edges. The 55-pound-capacity Scott tester was employed, and the autographic recording device was used to record the average load necessary to break. A planimeter was used in calculating the average tearing strength of the fabrics.

Ten samples of each fabric 1⅞ by 10 inches in size were abraded on the Wyzenbeck precision wear testmeter, with a monel-metal screen used as the abrasive surface. The fabrics were given 1,000 double rubs at 4 pounds pressure at an initial tension of 3 pounds. After abrasion, the tensile strength (strip) of the samples was determined by the methods already outlined.

CHEMICAL-PROPERTY DETERMINATIONS

Samples of fiber and fabrics in the various conditions studied were analyzed in duplicate for their moisture, ash, sulfur, and nitrogen content. Both fiber and yarn were cut into smal pieces to facilitate adequate sampling. Moisture was determined by drying to constant weight in a drying oven at 40° C. One-gram samples were ashed to constant weight and total ash recorded in percentage. The Parr Bomb was used in determining the total sulfur of 0.5-gm. samples, and the percentage of sulfur was calculated. The percentage of total nitrogen was determined upon 1-gm. samples by the Kjeldahl method, with copper sulfate used as the catalyst.

PRESENTATION AND DISCUSSION OF EXPERIMENTAL RESULTS

In the discussion of the results of this investigation, consideration is given first to the properties of the new and reworked fibers. Chemical determinations upon the fabrics after progressively greater numbers of dry cleanings were made, and the results of the application of the analysis of variance to the physical measurements of fabric strength are then discussed.

TABLE 2.—*Mean and standard-deviation values for length, crimp, diameter, and contour measurements of new and reprocessed wool*

Wool fiber	Length		Crimp per inch		Diameter		Contour ratio	
	Mean [1]	Standard deviation	Mean [1]	Standard deviation	Mean [2]	Standard deviation	Mean [2]	Standard deviation
	Inch	*Inch*	*Number*	*Number*	*Microns*	*Microns*		
New	2.49	0.96	13.34	3.03	21.16	5.03	1.25	0.143
Reprocessed	1.78	.88	11.95	5.00	25.72	7.22	1.25	.193

[1] 450 determinations.
[2] 1,000 determinations.

COMPARISON OF NEW AND REPROCESSED WOOL FIBERS

The physical characteristics of the new and reprocessed wool fibers are shown in table 2. From these data it may be seen that the average length of the new fiber was 40 percent greater than that of the reprocessed wool and the average number of crimps per inch was over 10 percent greater in the new wool. According to the blood system of grading wool, the virgin wool would be classed as fine and the reprocessed wool as half blood. No difference in average contour ratio was found in the wool. In all the physical measurements made, relative variability was greater in the reprocessed than in the new wool.

TABLE 3.—*Ash, nitrogen, and sulfur content of the new and reprocessed wool fiber, on a moisture-free basis*

Wool fiber	Ash	Nitrogen	Sulfur
	Percent	*Percent*	*Percent*
New	0.98	13.50	3.52
Reprocessed	.41	12.63	3.71

The ash, nitrogen, and sulfur content was determined for the new- and reprocessed-wool fibers with the results given in table 3.

The ash content of the new wool was more than twice that of the reprocessed wool, and the nitrogen content was approximately 1 percent greater. The sulfur content was 0.19 percent lower in the new wool.

COMPARISON OF FABRICS MANUFACTURED FROM NEW AND REPROCESSED WOOL

PHYSICAL AND CHEMICAL PROPERTIES OF FABRICS AS RECEIVED FROM THE MANUFACTURER

In the discussion of the manufacture of the fabrics it was noted that identical methods were used throughout in the preparation of yarns and in the weaving and finishing processes. When the finished materials were examined, it was evident that the fabrics produced from the various blends did not have the same properties. The data in table 4 shows that the average weight per square yard decreased as the percentage of reprocessed wool increased. Thickness and twist were approximately the same throughout the series, and the number of yarns per inch decreased slightly with increasing percentages of reprocessed wool.

In discussing the relative merits of the four fabrics, the fact that inherent differences were present in them must be kept in mind. Since correction factors accounting for the complexity of factors are not available, the data reported are those of the actual results obtained, the constant factors being identical manufacture and dry-cleaning processes rather than identity in finished fabric.

TABLE 4.—*Mean values for characteristics of the 4 fabrics containing different percentages of new and reprocessed wool fiber*

Fabric No.[1]	Weight per square yard [2]	Thickness	Yarns per inch		Shrinkage [3]		Twists per inch [3]	
			Warp	Filling	Warp	Filling	Warp	Filling
	Ounces	*0.001 inch*	*Number*	*Number*	*Percent*	*Percent*	*Number*	*Number*
100–0	7.92	32.2	44.3	36.2			11.7	12.4
100–15	8.75	35.4	45.2	38.5	5.0	1.2	12.5	12.8
100–30	8.94	36.5	45.9	39.3	6.2	1.2	12.8	12.9
100–45	8.48	36.0	45.3	39.3	6.2	1.2	12.9	12.8
75–0	7.71	32.8	43.3	35.9			12.2	12.4
75–15	8.45	36.0	44.2	37.9	3.8	1.2	12.3	12.4
75–30	8.69	36.4	44.8	38.0	6.2	1.2	12.7	12.4
75–45	8.90	36.2	44.7	38.3	6.2	1.2	12.6	12.5
50–0	7.36	33.0	43.0	35.4			12.4	12.5
50–15	7.77	35.2	43.9	37.2	3.8	1.2	12.6	12.6
50–30	8.29	35.4	44.5	38.5	6.2	1.2	12.5	12.6
50–45	7.76	35.2	43.9	38.2	6.2	1.2	12.5	12.6
25–0	6.71	31.6	42.9	35.3			12.1	12.4
25–15	7.01	33.8	43.5	38.2	3.8	1.2	12.0	12.2
25–30	7.32	33.2	43.7	37.8	5.0	1.2	12.2	12.4
25–45	7.28	33.6	43.4	38.2	5.0	1.2	12.3	12.7

[1] The numerals following the dash indicate the number of dry cleanings and pressings undergone by the fabrics.
[2] 13 percent regain.
[3] Caused by dry cleaning and pressing

Since fabric weight decreased progressively with increasing percentages of reprocessed wool, it must be concluded that there was more carding and spinning waste as the percentage of reprocessed wool was increased. In this same connection, a comparison of the average diameter of the fiber present in the finished fabrics is of significance. The results of this study are shown in table 5. From these data it is apparent that in the case of the 100-percent virgin fabric the manufacturing processes did not affect either the average diameter or the distribution as measured by the standard deviation. It would be anticipated that the average diameter of the wool present in the fabrics containing reprocessed wool would increase, approaching that of the reprocessed fiber as the percentage of reprocessed fiber became higher. However, as is shown in table 5, the diameter increased but slightly. Thus in the manufacturing processes the coarser reprocessed fiber must have been eliminated to a certain extent. Since the contour ratios of the new and the reprocessed fiber were the same, no change in contour ratio would be anticipated throughout the series of fabrics; and, in fact, the actual differences found are not to be considered significant from a practical standpoint.

TABLE 5.—*Diameter and contour ratios of the fibers in the new and reprocessed wool and in the manufactured fabrics*

Sample [1]	Diameter		Contour ratio	
	Mean	Standard deviation	Mean	Standard deviation
	Microns	*Microns*		
New fiber	21.16	5.03	1.25	0.143
Reprocessed fiber	25.72	7.22	1.25	.193
Fabric No.—				
100	21.30	5.16	1.24	.140
75	21.71	5.52	1.24	.142
50	21.77	5.73	1.25	.158
25	22.04	6.56	1.23	.139

[1] Size of sample, 1,000.

EFFECTS ON FABRICS OF DRY CLEANING AND PRESSING

In table 6 are shown the results of the ash, nitrogen, and sulfur analyses of the four fabrics as received from the manufacturer and after various numbers of dry cleanings and pressings. It will be noted that, with few exceptions, the tendency was for the percentage of ash to increase with dry cleaning. In all four fabrics there was a marked increase in nitrogen between the fifteenth and thirtieth dry cleanings, an increase which could not be accounted for on the basis of any of the other physical or chemical experimental results. It has

TABLE 6.—*Ash, nitrogen, and sulfur content on a moisture-free basis of the four fabrics containing different percentages of new and reprocessed wool fiber*

Fabric No.	Ash	Nitrogen	Sulfur	Fabric No.	Ash	Nitrogen	Sulfur
	Percent	*Percent*	*Percent*		*Percent*	*Percent*	*Percent*
100–0	0.48	13.55	3.34	50–0	0.64	13.50	3.47
100–15	.97	13.15	3.54	50–15	1.02	13.38	3.39
100–30	.94	15.83	3.37	50–30	.91	15.99	3.36
100–45	1.08	15.78	3.74	50–45	1.14	15.67	3.43
75–0	.66	13.58	3.63	25–0	.61	13.42	3.44
75–15	.83	13.07	3.59	25–15	.98	13.15	3.33
75–30	.91	15.66	3.58	25–30	.84	15.55	3.41
75–45	1.00	15.45	3.34	25–45	1.36	15.57	3.27

been suggested that accumulation of the paste soap might have been responsible, but no analysis of the soap is available. Sulfur determinations indicate that no fabric blend or treatment affected the results to a greater or less extent than any other throughout the series. In some instances a fabric sample had a higher sulfur content as a result of one stage of treatment, whereas in other fabrics this treatment apparently caused a lowering of the sulfur content.

In the discussion of the effects of abrasion and dry cleaning and pressing, statistical methods have been applied in the comparisons of the four fabrics in the various stages of treatment. All of the data reported in tables 7 to 10 are involved in the calculations.

TABLE 7.—*Mean and standard-deviation values for the yarn-strength and elongation measurements of the experimental fabrics as affected by dry cleaning and pressing*

Fabric No.[1]	Yarn strength				Yarn elongation			
	Warp		Filling		Warp		Filling	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
	Grams	*Grams*	*Grams*	*Grams*	*Centimeters*	*Centimeters*	*Centimeters*	*Centimeters*
100-0	311.2	52.02	287.6	55.90	5.09	0.929	5.06	0.890
100-15	337.9	49.52	285.7	49.49	4.88	.842	4.61	.874
100-30	319.5	52.45	327.9	47.61	4.67	1.023	4.86	.960
100-45	317.2	42.63	300.2	42.12	4.32	.857	4.51	.830
75-0	268.3	35.55	282.7	27.26	4.38	.883	4.76	.782
75-15	288.6	46.33	287.5	32.97	4.16	.876	4.39	.821
75-30	262.8	44.43	267.3	43.42	3.91	.869	4.01	.919
75-45	261.2	34.08	248.9	30.05	4.05	.634	4.18	.693
50-0	224.0	36.10	196.4	24.54	3.92	.781	3.83	.879
50-15	222.6	29.66	193.0	20.15	3.52	.665	3.68	.659
50-30	221.6	36.18	196.8	32.51	3.47	.790	3.69	.712
50-45	213.7	32.67	196.4	28.57	3.53	.669	3.25	.605
25-0	171.5	31.68	181.0	35.34	2.89	.693	3.27	.723
25-15	169.5	32.78	164.1	29.21	2.66	.661	2.91	.676
25-30	159.8	26.99	148.3	28.41	2.64	.625	2.65	.609
25-45	170.3	30.99	149.7	24.59	2.78	.676	2.79	.693

[1] Size of sample, 50.

TABLE 8.—*Mean and standard-deviation values for strip tensile-strength and elongation measurements of the experimental fabrics before and after abrasion*

BEFORE ABRASION

Fabric No.[1]	Strip breaking strength				Strip elongation			
	Warp		Filling		Warp		Filling	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Inches*	*Inches*	*Inches*	*Inches*
100-0	36.4	1.18	27.2	0.86	0.84	0.149	1.07	0.066
100-15	37.0	1.01	30.6	1.27	1.05	.202	1.08	.094
100-30	36.8	.68	30.9	1.39	.98	.081	1.10	.081
100-45	35.7	.95	28.4	1.31	.97	.066	1.06	.094
75-0	30.2	.63	24.1	.92	.71	.058	.99	.075
75-15	31.2	1.14	26.8	1.11	.85	.058	1.11	.128
75-30	30.4	1.17	25.7	1.93	.80	.066	.93	.316
75-45	31.2	1.18	23.6	1.02	.85	.100	.93	.316
50-0	25.7	.89	19.0	.67	.58	.094	.83	.081
50-15	27.0	.67	19.8	.53	.65	.058	.86	.047
50-30	26.1	1.22	21.4	.64	.70	.066	.88	.047
50-45	25.4	.88	20.0	.60	.66	.066	.81	.034
25-0	21.2	.47	15.1	.78	.44	.047	.63	.047
25-15	22.2	.75	17.5	1.29	.60	.000	.72	.081
25-30	21.6	1.14	16.0	.83	.62	.047	.72	.047
25-45	21.0	.68	16.0	.83	.62	.066	.73	.047

[1] Size of sample ,10.

TABLE 8.—*Mean and standard-deviation values for strip tensile-strength and elongation measurements of the experimental fabrics before and after abrasion*—Con.

AFTER ABRASION

Fabric No.[1]	Strip breaking strength				Strip elongation			
	Warp		Filling		Warp		Filling	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Inches*	*Inches*	*Inches*	*Inches*
100-0	35.6	0.63	28.7	1.36	0.79	0.088	1.01	0.111
100-15	37.0	1.01	31.2	1.51	.87	.066	.99	.058
100-30	37.0	.68	30.4	1.11	.98	.081	1.04	.066
100-45	35.4	.58	30.4	1.85	.91	.100	1.02	.081
75-0	30.2	1.09	25.3	.89	.65	.089	.84	.081
75-15	31.0	.55	26.6	1.46	.73	.066	.91	.075
75-30	30.6	.83	26.4	.98	.80	.081	.95	.058
75-45	31.1	1.93	26.8	1.51	.78	.066	.89	.075
50-0	26.8	.43	20.2	.79	.53	.047	.74	.047
50-15	26.8	.72	21.0	.91	.64	.047	.75	.075
50-30	26.5	.74	21.0	.53	.66	.047	.73	.047
50-45	25.8	1.00	21.8	.97	.69	.058	.72	.045
25-0	21.8	.75	16.0	1.05	.45	.058	.61	.058
25-15	21.6	.52	16.4	.81	.52	.047	.63	.047
25-30	21.3	.42	16.0	1.03	.54	.047	.60	.047
25-45	20.8	.89	16.6	.70	.55	.058	.61	.058

[1] Size of sample, 10.

TABLE 9.—*Mean and standard-deviation values for grab breaking-strength and elongation measurements of the experimental fabrics as affected by dry cleaning and pressing*

Fabric No.[1]	Grab breaking strength				Grab elongation			
	Warp		Filling		Warp		Filling	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Inches*	*Inches*	*Inches*	*Inches*
100-0	52.0	1.25	43.8	2.30	0.79	0.058	1.03	0.066
100-15	52.1	1.81	45.8	2.19	.82	.047	1.06	.066
100-30	53.7	2.10	47.8	2.83	.90	.081	1.16	.133
100-45	49.6	1.63	44.0	2.81	.90	.081	1.05	.100
75-0	42.5	2.51	35.4	2.40	.77	.094	.99	.075
75-15	42.9	1.37	40.4	1.45	.80	.081	.97	.081
75-30	42.5	1.58	37.0	1.82	.83	.066	.92	.047
75-45	42.0	1.05	37.0	1.95	.76	.066	.93	.066
50-0	35.6	2.77	29.0	2.03	.66	.081	.95	.145
50-15	35.9	1.85	29.1	1.43	.65	.058	.85	.088
50-30	35.5	1.81	29.5	1.65	.70	.047	.83	.066
50-45	34.5	1.03	28.8	1.77	.68	.094	.80	.094
25-0	27.0	1.04	22.6	1.10	.45	.058	.73	.066
25-15	27.8	.88	24.2	1.12	.55	.058	.73	.066
25-30	28.1	1.10	23.0	1.09	.54	.047	.69	.075
25-45	26.6	1.22	23.1	.97	.53	.047	.67	.047

[1] Size of sample, 10.

TABLE 10.—*Mean and standard-deviation values for the bursting-strength, bursting-elongation, and tearing-strength measurements of the experimental fabrics as affected by dry cleaning and pressing*

Fabric No. [1]	Bursting strength		Bursting elongation		Tearing strength			
					Warp		Filling	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
	Pounds	*Pounds*	*Inches*	*Inches*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
100-0	81.4	2.92	0.50	0.000	5.85	0.242	6.10	0.460
100-15	88.6	4.67	.52	.079	4.80	.350	5.05	.370
100-30	88.6	2.57	.50	.000	5.15	.338	4.85	.338
100-45	87.7	2.89	.50	.000	4.90	.316	4.50	.236
75-0	77.6	3.14	.52	.079	4.95	.160	4.80	.350
75-15	78.8	2.81	.48	.079	4.35	.242	4.20	.258
75-30	76.0	2.83	.42	.120	4.35	.242	4.40	.316
75-45	78.9	2.45	.48	.079	4.30	.258	4.35	.242
50-0	65.1	2.21	.48	.079	4.50	.236	4.40	.211
50-15	65.6	1.61	.40	.128	4.05	.160	3.75	.264
50-30	66.9	3.10	.45	.105	4.05	.100	3.65	.242
50-45	67.0	2.71	.48	.079	4.05	.285	3.85	.242
25-0	56.2	3.84	.48	.079	3.95	.160	4.20	.258
25-15	60.6	1.44	.48	.079	3.85	.242	3.65	.242
25-30	60.3	2.44	.50	.000	3.90	.316	3.80	.258
25-45	59.0	2.27	.40	.128	3.95	.285	3.75	.264

[1] Size of sample, 10.

After subjecting samples of each of the experimental fabrics to mechanical abrasion, strip tensile-strength samples were cut and tensile strength following abrasion for 1,000 double rubs was determined. The results of these measurements are recorded in table 8. "Student's" t test for significance of difference of means has been applied in comparing the strength and elongation values for the fabrics before and after the abrasion treatment (table 8). Nonsignificant differences were found in both warp and filling determinations of strength. In elongation measurements the means of both warp and filling determinations were found to differ significantly. Thus, with five exceptions, elongation was found to decrease after abrasion without causing a decrease in strength.

Since homogeneity of errors is assumed in the calculations of the analysis of variance, the χ^2 test was used to determine whether the variability of the strength and elongation measurements for the fabrics subjected to the various numbers of dry cleanings and pressings were homogeneous (Snedecor, *10*). The results indicated in table 11 show that this was true in all instances.

TABLE 11.—*Analysis of errors of strength and elongation measurements of the fabrics by means of the* χ^2 *test for homogeneity*

Measurement	χ^2 for—			
	Strength		Elongation	
	Warp	Filling	Warp	Filling
Yarn	3.99	4.45	2.86	2.62
Strip:				
Before abrasion	2.74	3.67	3.44	2.04
After abrasion	2.63	3.70	3.34	2.61
Grab	3.82	4.60	2.53	1.75
Bursting [1]	2.21		.50	
Tear	1.08	1.54		

[1] Fabric direction not involved in bursting-strength determination.

The analysis of variance suggested by Fisher (*4*) was applied to the measurements of yarn and fabric strength and elongation in order to test for significance of differences between fabrics and treatments (dry cleaning and pressing). There were 4 fabrics receiving 4 treatments, 10 measurements being made for fabrics and 50 for yarns. The degrees of freedom are shown in table 12.

TABLE 12.—*Degrees of freedom involved in the analysis of variance of the measurements of yarn and fabric strength and elongation*

Variation due to—	Degrees of freedom	
	Fabric studies	Yarn studies
Blend	3	3
Treatment	3	3
Blend × treatment	9	9
Residual (error)	144	784
Total	159	799

In the analysis of the data based upon these tests of significance (table 13), consideration is given first to the cases in which the residual component is used as error and finally to those in which blend × treatment is used as error. If the residual is used as error, the interpretation applies to the specific fabrics and treatments involved in this study. However, it is of interest to expand the interpretation to

TABLE 13.—*F values by means of the analysis of variance for yarn- and fabric-strength, and for yarn- and fabric-elongation determinations, using residual and interaction as errors*

STRENGTH DETERMINATIONS

Measurement and source of variation	Degrees of freedom	*F* values			
		Warp		Filling	
		Residual as error	Interaction as error	Residual as error	Interaction as error
Yarn strength:					
Blend	3	[1] 565.84	[1] 310.82	[1] 655.32	[1] 64.55
Treatment	3	[1] 5.66	3.11	[1] 5.25	.52
Blend × treatment	9	1.82		[1] 10.15	
Strip strength before abrasion:					
Blend	3	[1] 1,857.98	[1] 1,074.97	[1] 1,166.64	[1] 184.96
Treatment	3	[1] 10.90	[2] 6.30	[1] 45.25	[1] 7.17
Blend × treatment	9	1.73		[1] 6.31	
Strip strength after abrasion:					
Blend	3	[1] 2,076.27	[1] 589.05	[1] 1,134.07	[1] 773.76
Treatment	3	[1] 6.15	1.74	[1] 11.44	[1] 7.80
Blend × treatment	9	[1] 3.52		1.46	
Grab strength:					
Blend	3	[1] 1,573.91	[1] 869.96	[1] 1,069.77	[1] 476.14
Treatment	3	[1] 8.84	[2] 4.89	[1] 12.32	[2] 5.48
Blend × treatment	9	1.81		[2] 2.25	
Tearing strength:					
Blend	3	[1] 181.91	[1] 32.09	[1] 165.05	[1] 23.03
Treatment	3	[1] 39.66	[1] 7.00	[1] 62.37	[1] 8.70
Blend × treatment	9	[1] 5.67		[1] 7.17	
Bursting strength: [3]					
Blend	3	[1] 681.38	[1] 201.47		
Treatment	3	[1] 11.25	3.29		
Blend × treatment	9	[1] 3.38			

See footnotes at end of table.

TABLE 13.—*F values by means of the analysis of variance for yarn- and fabric-strength, and for yarn- and fabric-elongation determinations, using residual and interaction as errors*—Continued

ELONGATION DETERMINATIONS

Measurement and source of variation	Degrees of freedom	*F* values			
		Warp		Filling	
		Residual as error	Interaction as error	Residual as error	Interaction as error
Yarn elongation:					
Blend	3	[1] 230.94	[1] 137.67	[1] 218.44	[1] 102.50
Treatment	3	[1] 11.45	[2] 6.83	[1] 18.15	[1] 8.52
Blend × treatment	9	1.68		[2] 2.13	
Strip elongation before abrasion:					
Blend	3	[1] 155.25	[1] 56.54	[1] 204.26	[1] 54.50
Treatment	3	[1]20.36	[1] 7.44	[1] 8.35	2.23
Blend × treatment	9	[1] 2.74		[1] 3.75	
Strip elongation after abrasion:					
Blend	3	[1] 223.95	[1] 229.54	[1] 286.07	[1] 160.64
Treatment	3	[2] 3.55	3.64	1.53	.86
Blend × treatment	9	.98		1.78	
Grab elongation:					
Blend	3	[1] 186.48	[1] 93.14	[1] 137.27	[1] 42.62
Treatment	3	[1] 8.43	[2] 4.21	[2] 3.80	1.18
Blend × treatment	9	[2] 2.00		[1] 3.22	
Bursting elongation: [3]					
Blend	3	[2] 3.41	1.67		
Treatment	3	1.13	.55		
Blend × treatment	9	[2] 2.03			

[1] Exceeds 1-percent point.
[2] Exceeds 5-percent point.
[3] Fabric direction not involved in bursting-strength determinations.

indicate the general effects of mixing new and reprocessed wool and the effect of dry-cleaning and pressing processes. As has been suggested by Immer (*6*), the interaction is the proper error in this case.

When the residual is used as error, the blends are found to differ significantly in strength and elongation in all of the yarn and fabric measurements (table 13). Highly significant differences would be anticipated by examination of tables 7 through 10, reporting the actual strength and elongation results. It may further be noted from these data that, in general, strength decreased regularly as the percentage of reprocessed wool became greater.

With the exception of bursting elongation, in which significant differences were found between the blends, highly significant differences between blends were present. Thus, as is shown in table 7 through 10, elongation decreased with increasing percentages of reprocessed fiber.

If the residual component is used as error in testing for the effects of dry cleaning and pressing (treatment), highly significant differences are found in all instances of strength determinations and in two instances of elongation determinations. This may be seen by examination of the data in table 13.

If consideration is given to the totals for blends receiving the same treatment, the reason for the existence of significant differences between treatments becomes evident. The strength measurements

are found to be greater at 15 dry cleanings, with progressively decreasing values after 30 and 45 dry cleanings in five cases; values decrease throughout in the case of the tearing-strength measurements in the filling direction; increase at 15 dry cleanings, decrease at 30, and again increase at 45, following abrasion, in the filling direction; increase progressively through 30 dry cleanings and decrease at 45 dry cleanings in grab and abrasion measurements of the warp; while two measurements, tearing strength of the warp and filling, show marked decreases after 15 dry cleanings, remain approximately the same through 30 dry cleanings, and then decrease after 45 dry cleanings.

The effects of dry cleaning and pressing on elongation are not necessarily of the same order as those on the strength measurements. The totals are found to increase after 15 dry cleanings and then gradually to decrease in the filling direction of the grab determinations; to increase at 15 dry cleanings and remain approximately the same throughout in the warp direction of the strip determinations; to increase through 30 dry cleanings and decrease at 45 dry cleanings in the warp and filling abrasion and warp grab measurements; and to decrease progressively in the remaining four instances.

The third question of interest is whether the effect of treatment upon the four blends was similar. The test of significance is made by dividing the mean square for interaction by the error mean square. These results are also recorded in table 13. From this table it may be seen that in the strength measurements highly significant interactions are found in six instances, significant interactions in one instance, and nonsignificant interations in four instances. Treatment does not affect elongation significantly in three cases, while significant differences are found in three instances, and highly significant differences in three others.

A detailed study of the means indicates the reason for significant differences in the results. For example, the mean of the warp abrasion-strength measurements for fabric 100 is greater at 15 dry cleanings, the same at 30 as at 15 dry cleanings, and lower at 45 than at 30 dry cleanings; for fabric 75 it is lower at 15, lower still at 30, and at 45 approximately the same as at 15; for fabric 50 it is the same at 15 as before dry cleaning, slightly lower at 30, and lower still at 45; and for fabric 25 it is slightly lower after each series of dry cleanings. Similar fabric behavior is found in the elongation measurements, where significant or highly significant results are recorded. While each individual fabric does not vary a great deal in its reaction to treatment, the dissimilar reaction of the other fabrics results in the significant differences found between treatments.

Thus, analysis of the data with the residual used as error leads to the conclusions that the four fabrics were significantly different in measurements of strength and elongation; the treatments to which the fabrics were subjected were significantly different; and in some instances the four fabrics did not react similarly to treatment as registered in terms of strength and elongation. Tables of the actual results show that the fabrics decreased in strength in progressing from the 100 percent new-wool fabric to the 25 percent new-wool

fabric when similar manufacturing processes were employed. Elongation likewise decreased as the percentage of reprocessed fiber was increased. Dry cleaning and pressing increased strength in some instances and lowered it in others.

As is suggested above, it is desirable to expand the interpretation of the data to include an analysis of the effects of dry cleaning and pressing on flannel fabrics containing different percentages of new and reprocessed wool. For this purpose the interaction of blend × treatment is used as error. The results of these calculations are also reported in table 13. In making these interpretations, however, it is recognized that the inclusion of a larger number of blends and treatments would have been desirable and that the results are applicable only to blends in which the fiber properties are those found in this study. Thus all blends of new and reprocessed wool fiber would not necessarily produce fabrics having the properties found in this study.

Upon examination of the *F* values it may be seen that, regardless of treatment, varying the blend of new and reprocessed fibers appreciably in flannel fabrics yielded fabrics that differed significantly in strength and elongation. One exception to this finding was the elongation measurements during the determination of bursting strength, where it was found that all blends behaved similarly.

A second determination of importance involved testing for the significance of fabric treatment. In the strength measurements it is found that, regardless of blend, treatment effect is highly significant in four cases, significant in four, and nonsignificant in three. With the exception of tearing strength, in which both warp and filling directions are highly significant, the filling direction of the fabrics shows a greater tendency than the warp to give highly significant results. In several instances fabrics that are significantly different in one fabric direction are nonsignificant in the other. Thus the results of the application of the test of significance for the effects of fabric treatment on the strength of the fabrics are mixed.

In the effect of treatment on fabric elongation it is found that, regardless of blend, treatment affects elongation highly significantly in two instances, significantly in two, and nonsignificantly in five.

In summarizing the findings based on the second method of interpretation, it is shown that blending new and reprocessed wool fiber of the types employed in the present study in varying proportions and subjecting them to the same manufacturing processes resulted in fabrics of different strength and elongation, regardless of subsequent dry-cleaning and pressing processes. Dry cleaning and pressing the fabrics affected strength and elongation significantly in some instances and nonsignificantly in others, regardless of the blend.

SUMMARY

Wool flannel fabrics containing different blends of new and reprocessed fiber were manufactured, using identical spinning, weaving, and finishing processes. Chemical and physical tests were applied to the fabrics as received from the manufacturer and after varying numbers of commercial dry-cleanings and pressings.

Comparisons of the fiber qualities of the new and the reprocessed wool indicated that the new wool was finer, longer, and crimpier. No difference in average contour ratio was found.

Ash and nitrogen, were greater in the new fiber whereas the sulfur content was lower.

Examination of the fundamental properties of the four fabrics manufactured indicated that, when fibers of the nature described were used for blending, an increase in the percentage of reprocessed wool resulted in an appreciable decrease in the weight per square yard, though the number of yarns per inch decreased only slightly and the twist remained approximately the same.

Comparisons between the diameter of the fibers in the finished fabrics and those in the new and reprocessed wool from which the fabrics were made indicated that the coarser reprocessed fiber must have been eliminated to a certain extent during manufacture.

Determinations of the moisture, ash, nitrogen, and sulfur content of the fabrics before and after dry cleaning and pressing showed that the ash tended to increase with dry cleaning; that neither blend nor treatment affected the sulfur content appreciably; and that in all blends there was a marked increase in nitrogen between the fifteenth and thirtieth dry cleanings.

Statistical methods were applied in the analyses of the effects of abrasion and dry cleaning and pressing on the four fabrics. Non-significant differences in strength between unabraded fabrics and fabrics abraded 1,000 times were found. However, there was a decrease in elongation following abrasion.

When the interpretation of the results of the application of the analysis of variance was limited to comparisons between the four fabrics studied, it was found that the fabrics were significantly different in strength and elongation; the treatments to which they were subjected were significantly different; and in some instances they did not react similarly to treatment. Expanding the interpretation to indicate the general effects of blending new and reprocessed wool of the types used in this study in manufacturing flannel fabrics resulted in the conclusion that fabrics of different strength and elongation are produced, regardless of subsequent dry cleaning and pressing processes to which they may be exposed. Thus, regardless of the method of interpretation, it was found that increases in the percentage of the reprocessed wool used in this study resulted in corresponding decreases in fabric strength and elongation. The effects of dry cleaning and pressing were mixed and therefore inconclusive.

LITERATURE CITED

(1) Anonymous.
1935. new cross-sectioning device. Textile Res. 5: 580.

(2) American Society for Testing Materials.
1939. a. s. t. m. standards on textile materials . . . 324 pp., illus. Philadelphia.

(3) Barker, Aldred E.
1933. report to the new zealand government on english leicester (38's/42's), romney 44's/46's, romney 46's/48's and corriedale 50's/56's, wools. Textile Inst. Jour. 24: T57–T58, illus.

(4) Fisher, R. A.
1932. statistical methods for research workers. Ed. 4, rev. and enl., 307 pp., illus. Edinburgh and London.

(5) Hays, Margaret B., Elmquist, Ruth E., and Hardy, J. I.
1937. a serviceability test on blankets made from four blends of wool. U. S. Dept. Agr. Tech. Bul. 572, 24 pp., illus.

(6) Immer, F. R., Hayes, H. K., and Powers, LeRoy.
1934. statistical determination of barley varietal adaptation. Amer. Soc. Agron. Jour. 26: 403–419.

(7) LEEDS UNIVERSITY, TEXTILE INDUSTRIES DEPARTMENT.
1924. AN INVESTIGATION INTO THE NATURE OF BRITISH PEDIGREE WOOLS, THEIR SPINNING AND THEIR WEAVING QUALITIES. Jour. Textile Sci., Spec. Issue 1: 1–34, illus.

(8) ———
1925. II. AN INVESTIGATION INTO THE NATURE OF BRITISH PEDIGREE WOOLS, THEIR SPINNING AND THEIR WEAVING QUALITIES. Jour. Textile Sci., Spec. Issue 2: 1–31, illus.

(9) ———
1926. AN INVESTIGATION INTO THE NATURE OF BRITISH PEDIGREE WOOLS, THEIR SPINNING AND THEIR WEAVING QUALITIES. III. THE MANUFACTURING PROCESSES. Jour. Textile Sci. 1: 13–16, illus.

(10) SNEDECOR, GEORGE W.
1937. STATISTICAL METHODS APPLIED TO EXPERIMENTS IN AGRICULTURE AND BIOLOGY. 341 pp., illus. Ames, Iowa.

(11) TOWNSEND, SIDNEY.
1938. FURTHER ADVANCES IN THE LENGTH ANALYSIS OF WOOL. Textile Inst. Jour. 29: T55–T66, illus.

INHERITANCE OF RESISTANCE TO SIX PHYSIOLOGIC RACES OF BEAN RUST[1]

By W. J. ZAUMEYER, *pathologist*, and L. L. HARTER, *senior pathologist, Division of Fruit and Vegetable Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture* [2]

INTRODUCTION

The presence of 2 physiologic races of the bean rust organism (*Uromyces phaseoli typica* Arth.) was first demonstrated by Harter, Andrus, and Zaumeyer (*6*).[3] Later, Harter (*5*) and Harter and Zaumeyer (*7*) reported 18 additional ones. They showed that certain varieties and strains of beans (*Phaseolus vulgaris* L.) were resistant to a number of these physiologic races whereas other varieties were susceptible.

Wingard (*13*) studied the inheritance of rust resistance and showed in two different crosses involving resistance and susceptibility that resistance was dependent on a single dominant factor, the F_2 results showing a ratio of 3 resistant plants to 1 susceptible. He made no counts in the F_3 generation, but reported that the susceptible F_2 plants bred true for susceptibility in the F_3 generation and that the F_2 resistant plants segregated for resistance and susceptibility. It is assumed that Wingard worked with a single physiologic race, and his results are accepted as proof of the mode of inheritance for the bean varieties and the race of rust he used. With the identification of a number of physiologic races of bean rust since the publication of his results, the question naturally arose as to whether progenies of various bean crosses show the same genetic behavior with reference to other races of rust. Investigations (*1, 2, 4, 11*) on the stem rust of wheat (*Puccinia graminis tritici* Eriks. and Henn.) showed that resistance was not inherited alike by all varieties and to various races of the parasite. This paper deals with the inheritance of resistance, in a number of bean hybrids, to several of the physiologic races of the bean rust organism.

MATERIALS AND METHODS

The rust material used in these studies was either collected by the writers in several sections of the United States or sent to them by various pathologists throughout the country. Later a number of different bean varieties were inoculated with these strains for purposes of identification and to test the purity of the particular physiologic race. If more than one race were present, each was isolated and pure-lined by using spores of a single sorus. Each race was then increased by the inoculation of some susceptible variety and then reinoculated to the differential varieties for the redetermination of purity.

[1] Received for publication June 6, 1941.
[2] The writers are indebted to F. J. Stevenson and LeRoy Powers, senior geneticists, both of this Division, for assistance in the interpretation of certain data, and to V. R. Boswell, principal horticulturist, of this Division, for suggestions and criticisms in the preparation of the manuscript.
[3] Italic numbers in parentheses refer to Literature Cited, p. 621.

When this was accomplished, the infected leaves were collected, dried for a few days between blotting papers, and then stored in envelopes in a refrigerator at −6° C. until needed for inoculation purposes. The physiologic races involved in this study were 1, 2, 6, 11, 12, and 17, and the identical lines of these races were maintained throughout the course of the experiments. In some cases slight race mixtures occurred in the inoculated F_3 plants, but these were in such reduced numbers that they were readily detectable and did not in any way confuse the results. For example, certain plants from a homozygous susceptible line exhibited a very small number of lesions of the resistant type, whereas the great majority of lesions were of the susceptible type, indicating that the resistant lesions were possibly produced by a race of the rust unlike the one producing the large pustules. Similarly, in certain homozygous resistant and heterozygous lines the predominating lesions were of the resistant type, but occasionally a small percentage of the pustules of the extremely susceptible type were noted; this indicated a slight race mixture.

The bean varieties or strains (table 1) used for differentiating the several physiologic races were as follows: (1) U. S. No. 3, a white-seeded Kentucky Wonder type; (2) Small White (*California*); (3) Pinto; (4) No. 765,[4] a Kentucky Wonder Wax selection; (5) No. 780,[4] a white-seeded Kentucky Wonder strain; (6) No. 814,[4] a brown-seeded Kentucky Wonder type. These varieties and those used for hybridization were inoculated in progeny tests and were found to breed true for resistance and susceptibility. The seed was grown by the writers at Greeley, Colo. In order to study the mode of inheritance of resistance to several of the physiologic races of bean rust, four different crosses involving six bean varieties and strains were made between certain varieties that were resistant to some of the races and those that were susceptible, and later the progenies were tested with the six selected physiologic races of the organism. One of the determining factors underlying the choice of the physiologic races for study was the reaction of the differential varieties whose resistance and susceptibility to these races had previously been determined. By a consideration of these factors it was believed that a fairly reliable cross section of the reaction to the six races chosen would be obtained, or at least enough would be learned about them to determine whether the hybrids that were inoculated agreed or differed in their mode of inheritance.

TABLE 1.—*Reaction of differential bean varieties and strains to 6 selected physiologic races of bean rust*

Differential variety or strain	Infection grade [1] produced by physiologic race—					
	1	2	6	11	12	17
U. S. No. 3	2	10	[2] 5–6/3	10	10	10
Small White (*California*)	9	8	9	9	10	1
Pinto	10	10	10	10	10	10
No. 765	1	1	2	6	2	5
No. 780	1-2	1	2	6	3	1
No. 814	1	0	9	10	0	0

[1] Infection grades range from 0 for immunity to 10 for highest degree of susceptibility.
[2] The fractional expression of grade indicates unequal size of pustules on upper and lower sides of leaf.

[4] Numbers carried in the files of the writers.

Hybridization was done under controlled greenhouse conditions. The parents and the crosses are listed in tables 2 and 3. Instead of inoculating the F_1 plants, the seed was increased under field conditions at Greeley, Colo. The environmental conditions of low humidities and high temperatures that prevail in Colorado and the danger of contamination of the physiologic races made it inadvisable to test the plants in the F_1 generation. The F_2 plants were inoculated under greenhouse conditions at Beltsville, Md. The seed was planted in 4-inch pots, and when the primary leaves were about three-fourths grown they were inoculated with the particular race of rust to be investigated by spraying their upper sides with a spore suspension.

At the same time a set of differential varieties was also inoculated to be certain of the purity of the particular race. The inoculated plants were then placed in a large chamber where the humidity was maintained at about 95 percent. After 24 to 48 hours in this chamber, they were removed and placed in greenhouse benches at a temperature varying from 75° to 80° F. At the end of 14 days, the grades of infection were recorded and the plants were labeled as to their reaction to the physiologic race of rust involved. Some of the hybrid plants of all classes were transplanted to greenhouse benches and allowed to grow to maturity. The seed harvested from the transplanted F_2 plants was grown later, and the plants were tested under greenhouse conditions for the F_3 data. The F_2 plants selected to give rise to the F_3 families were chosen at random within the resistant and susceptible classes. The F_3 families resulting from these selected F_2 plants were inoculated, and the results obtained were used to verify the F_2 data.

TABLE 2.—*Reaction of parental bean varieties and strains to 6 selected physiologic races of bean rust*

Variety or strain	Infection grade produced by physiologic race—					
	1	2	6	11	12	17
No. 765	1	1				
Pencil Pod Black Wax	10	10				
No. 780		1		6		
Pinto		10	10	10	10	10
Cranberry			0			
No. 192–48 [1]					0	0

[1] A strain closely related to No. 814, one of the differential varieties.

All of the F_2 plants that were inoculated with the six rust races were tested in the spring of 1938 and 1939. Most of the F_3 plants of the various hybrids were tested in the fall of 1939 and the first 3 months of 1940, when conditions were not as favorable for the development of the host and fungus as they were when the F_2 plants were inoculated.

The method used in identifying the various physiologic races was described by Harter and Zaumeyer (*7*) and will be reviewed only briefly. The scale (table 1) for relative resistance or susceptibility ranges from 0 to 10 and is based on the size of the sori. Under very favorable conditions for growth, readings lower than 5 (see figs. 1, *A*; 5, *A*; 7, *B*) denote grades of resistance; those from 5 to 10 (see figs. 1, *B*; 6, *A*) represent grades of susceptibility. There appears to be

no trace of mycelial invasion in the host tissue of plants rated 0 (see fig. 3, *A*), and they are consequently regarded as immune. A grade of 1 (see fig. 1, *A* and *C*) denotes a very high degree of resistance with the production of small to medium hypersensitive necrotic areas on the leaves without the formation of uredospores. A plant in grade 2 is still considered highly resistant, but a small number of uredospores are produced in the hypersensitive necrotic lesions. Plants with ratings of grade 3–4 (see figs. 5, *E*; 6, *D*) are moderately resistant, and the sori on the leaves are comparatively small. Plants rated grade 5 or above are regarded as being in the susceptible class, the pustules becoming progressively larger until the extremely susceptible grade 10 (see fig. 2, *B*) is reached. Table 1 shows that each physiologic race can be readily identified from its degree of infectivity on the several differential bean varieties.

The ratings in all classes were found to vary somewhat with changes in environmental conditions. Under favorable conditions, such as bright sunlight and a moderately high temperature (20° to 30° C.) following infection, the various physiologic races produced their maximum development, but during dark, cool weather or at temperatures above 32° the lesions were usually subnormal in size. For example, a variety rating grade 1 or 2 under favorable environment for the fungus may show a 0 or 1 rating, respectively, under adverse conditions. This would also be true for other grades, as, for example, a variety showing a 9 to 10 rating under good conditions might show only 7 to 8 under conditions adverse for the rust or host.

After establishing the purity of the several physiologic races, the parents were inoculated to determine their reaction to the six selected races of rust. These data are recorded in table 2.

The data recorded in this paper were subjected to the χ^2 test for goodness of fit. This test was applied independently to F_2 families from individual F_1 plants and to F_3 families from F_2 plants and also to the totals of a number of tested families according to Fisher's (*3*) statistical methods.

EXPERIMENTAL RESULTS

REACTION OF F_2 GENERATION

The F_1 plants were not inoculated but were grown under field conditions in order to obtain large seed populations. From 160 to 593 plants in the several F_2 progenies were inoculated (tables 3 and 4). No test was made with reciprocal crosses. An analysis of the data (table 3) shows that with races 1, 2, 6, and 12, resistance was dominant to susceptibility, with a 3:1 segregation in the F_2 generation, indicating a single-factor difference. With races 11 and 17, incomplete dominance is shown by the segregation of resistant, intermediate, and susceptible plants in the ratio of 1:2:1 (table 4). The χ^2 values indicated that the observed data fit the calculated quite closely in all but one instance. Three progenies of the cross Pinto × No. 780 inoculated with race 2 showed a fairly good fit to a 3:1 ratio when the χ^2 value (6.751)[5] was computed for the sum of the values of the individual

[5] 5-percent point = 7.815.

families. The χ^2 value for the total population of the 3 families was 6.158 [6] (1 degree of freedom), which indicated a rather poor fit to this ratio. The deviations in the 3 families were all minus but nonsignificant. Because of the cumulative effect of these deviations, the total deviation was significant, thus accounting for the high χ^2 value.

TABLE 3.—*Reaction of F_2 progenies to physiologic races 1, 2, 6, and 12*

Cross	Progenies	Rust race No.	Plants inoculated			Total χ^2 of individual progenies [1]		χ^2 calculated on total of each phenotype in all families [2]
			Total	Resistant (grade 1)	Susceptible (grade 10)	Calculated	5-percent point	
	Number		*Number*	*Number*	*Number*			
Pencil Pod Black Wax × No. 765:								
Observed	4	1	264	200	64	0.788	9.488	0.080
Calculated 3:1 ratio				198	66			
Pencil Pod Black Wax × No. 765:								
Observed	4	2	593	448	145	1.876	9.488	.095
Calculated 3:1 ratio				444.75	148.25			
Pinto × No. 780:								
Observed	3	2	243	199	44	6.751	7.815	6.157
Calculated 3:1 ratio				182.25	60.75			
Cranberry × Pinto:								
Observed	2	6	370	278	92	.926	5.991	.004
Calculated 3:1 ratio				277.5	92.5			
Pinto × No. 192-48:								
Observed	3	12	465	359	106	2.554	7.815	1.205
Calculated 3:1 ratio				348.75	116.25			

[1] Degrees of freedom = number of progenies.
[2] 1 degree of freedom; 5-percent point = 3.841.

TABLE 4.—*Reaction of F_2 progenies to physiologic races 11 and 17*

Cross	Progenies	Rust race No.	Plants inoculated				Total χ^2 of individual progenies [1]	χ^2 calculated on each phenotype in all families [2]
			Total	Resistant (grade 1)	Intermediate (grade 5–6)	Susceptible (grade 10)		
	Number		*Number*	*Number*	*Number*	*Number*		
Pinto × No. 780:								
Observed	3	11	160	40	78	42	3.383	0.150
Calculated 1:2:1 ratio				40	80	40		
Pinto × No. 192-48:								
Observed	3	17	461	127	222	112	6.033	1.603
Calculated 1:2:1 ratio				115.25	230.5	115.25		

[1] Degrees of freedom = number of progenies; 5-percent point = 7.815.
[2] 2 degrees of freedom; 5-percent point = 5.991.

REACTION TO INDIVIDUAL RACES

RUST RACE 1

Of 44 resistant families (table 5) derived from plants inoculated with rust race 1 in F_2 and tested with the identical race in F_3, 19 were homozygous for resistance and 25 were heterozygous. This is a

[6] 5-percent point = 3.841.

fairly close fit to a 1:2 ratio with a χ^2 value of 1.920.[7] The segregation of resistant and susceptible plants (fig. 1, *C* and *D*) in the 25 heterozygous families is a good fit to a 3:1 ratio. The total χ^2 values of the individual families is 23.216 [8] for 25 degrees of freedom, and the χ^2 value for the total population of all the families is 2.290 [7] for 1 degree of freedom.

The progenies from 10 F_2 selfed susceptible plants were homozygous for susceptibility. These results contribute additional evidence to support the single-factor hypothesis.

Rust Race 2

Of 54 resistant (fig. 2, *C*) families (table 5) derived from F_2 plants inoculated with rust race 2 and tested with the identical race in F_3, 20 were homozygous for resistance and 34 heterozygous. This segregation is likewise a good fit to a 1:2 ratio with a χ^2 value of 0.218.[7] The 34 heterozygous families segregated in a 3:1 ratio (table 5). The total χ^2 values of the individual families is 44.171 [9] for 34 degrees of freedom. The χ^2 value for the total number of tested plants (1 degree of freedom) is 9.471,[7] which showed a poor fit to a 3:1 ratio. An examination of the data recording the reaction of each individual family but not listed in this paper showed that only 1 family deviated significantly from the calculated. A few others showed fairly large but nonsignificant deviations. The deviations, however, in 25 of the 34 families were in one direction (minus), which accounted, in part, for the high χ^2 value for the total number of plants tested.

Eleven families that were susceptible (fig. 2, *D*) in F_2 proved to be homozygous for susceptibility in F_3.

TABLE 5.—*Reaction to physiologic races 1, 2, and 6 of F_3 progenies descended from F_2 hybrids inoculated with the respective races*

Physiologic race and classification of plants in F_3 generation	Families tested	Plants inoculated			Total χ^2 of individual families [1]	χ^2 of total of each phenotype in all families [2]
		Total	Resistant	Susceptible		
Race 1:	*Number*	*Number*	*Number*	*Number*		
Homozygous resistant (grade 1–2)	19	888	888	0		
Heterozygous resistant (grade 1–2)—						
Observed	25	1,232	947	285	[3] 23.216	2.290
Calculated 3:1 ratio			924	308		
Race 2:						
Homozygous resistant (grade 1–2)	20	773	773	0		
Heterozygous resistant (grade 1–2)—						
Observed	34	1,567	1,228	339	[4] 44.171	9.471
Calculated 3:1 ratio			1,175.25	391.75		
Race 6:						
Homozygous resistant (grade 1–2)	19	598	595	[5] 3		
Heterozygous resistant (grade 1–2)—						
Observed	41	1,844	[6] 1,429	415	[7] 42.824	6.120
Calculated 3:1 ratio			1,383	461		

[1] Degrees of freedom = number of progenies.
[2] 1 degree of freedom; 5-percent point = 3.841.
[3] 5-percent point = 37.652.
[4] Equals 13-percent point.
[5] Probably due to seed mixture.
[6] Among resistant plants, 175 severely variegated.
[7] Equals 40-percent point.

[7] 5-percent point = 3.841.
[8] 5-percent point = 37.652.
[9] Equals 13-percent point.

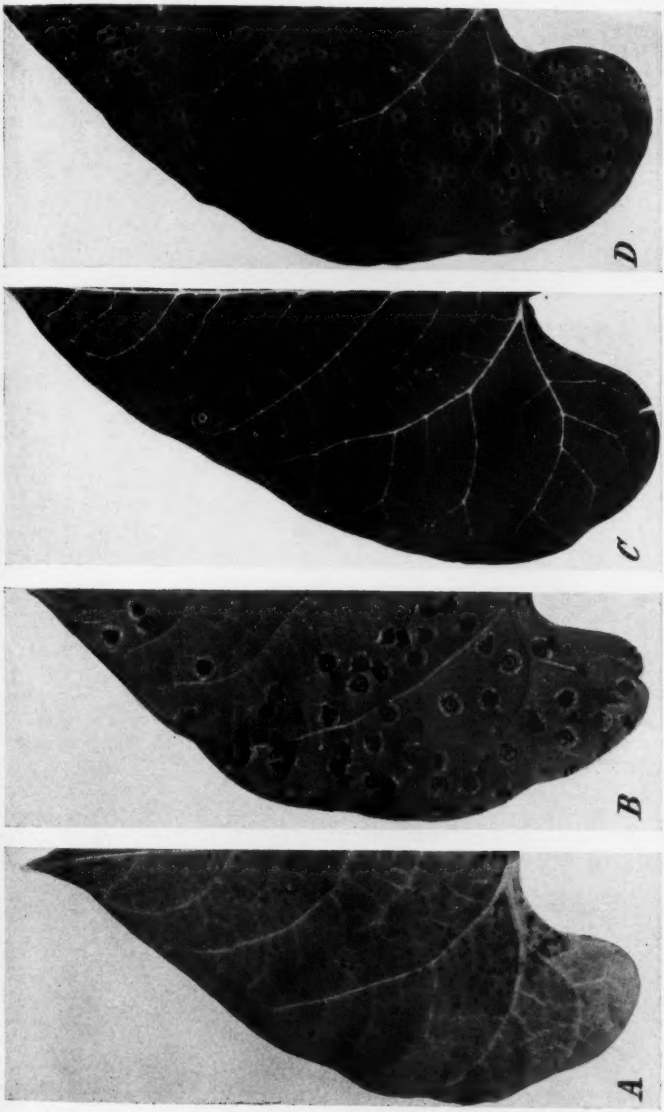


FIGURE 1.—Host reaction to race 1: *A*, Grade 1 on No. 765; *B*, grade 10 on Pencil Pod Black Wax; *C*, grade 1 on F_2 hybrid of cross Pencil Pod Black Wax × No. 765; *D*, grade 10 on another hybrid of same cross.

FIGURE 2.—Host reaction to race 2: *A*, Grade 1 on No. 780; *B*, grade 10 on Pinto; *C*, grade 1 on F_2 hybrid of cross Pinto × No. 780; *D*, grade 10 on another hybrid of same cross.

Rust Race 6

The F_2 progenies inoculated with race 6 (table 3) segregated in a ratio of 3 resistant plants to 1 susceptible (fig. 3, *C* and *D*). A few

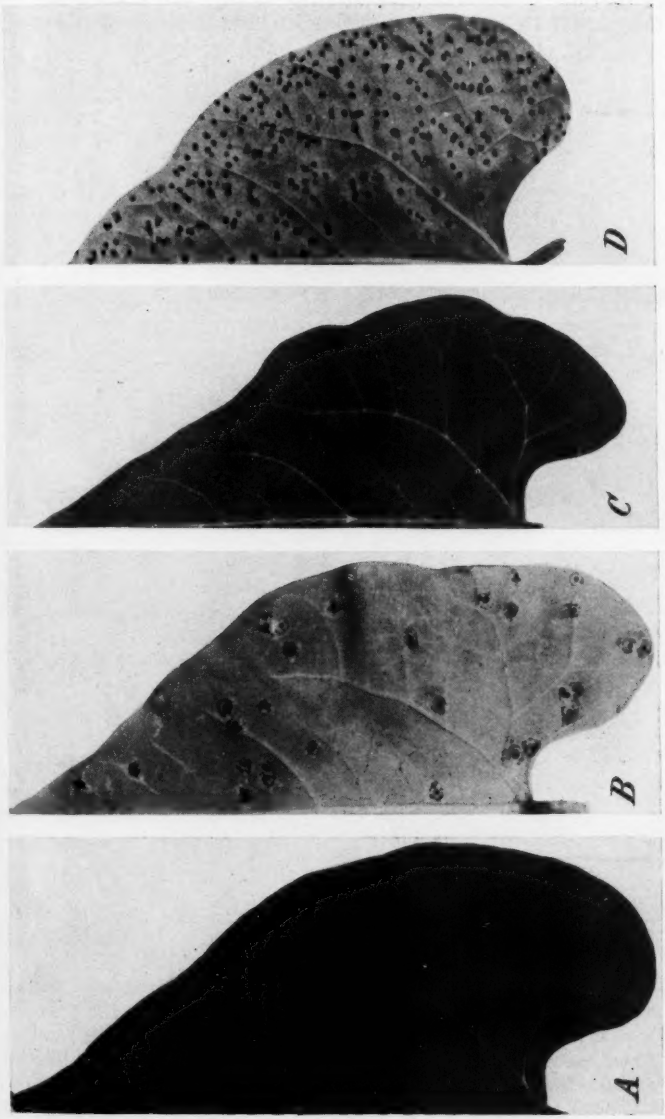


Figure 3.—Host reaction to race 6: *A*, Grade 0 on Cranberry; *B*, grade 10 on Pinto; *C*, grade 0 on F_2 hybrid of cross Cranberry × Pinto; *D*, grade 10 on another hybrid of same cross.

plants manifested a leaf variegation (fig. 4, *B* and *C*), which was described earlier by the senior writer (*14*) as a heritable abnormality

resembling mosaic. The mildly variegated plants showed a subnormal grade of infection (fig. 4, *C*), whereas those severely variegated showed no infection (fig. 4, *B*). Since the number of such plants was small, the ratio of resistance to susceptibility was not greatly altered. In 1 progeny there were 14 variegated plants, 3 of which showed a

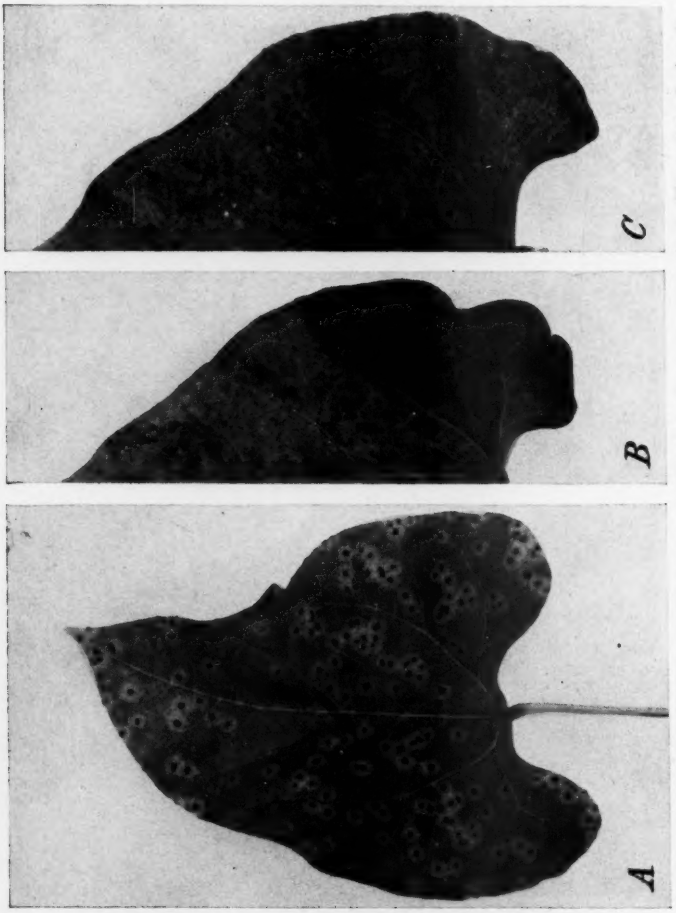


FIGURE 4.—Host reaction of normal and variegated leaves to race 6: *A*, Normal leaf showing abundance of pustules of grades 9 to 10; *B*, grade 0 on seriously variegated leaf; *C*, variegated leaf showing a few pustules of grades 8 to 9.

very serious chlorophyll deficiency; in another, 18 plants were variegated, but none of them were seriously affected.

Variegated plants are deficient in chlorophyll, the degree depending upon the extent of the variegation (fig. 4, *B* and *C*). It is likely that the mycelium of a germinating spore enters the host through a stoma, but its progress and development from this point apparently are dependent upon the amount of chlorophyll present in the leaf. In a seriously variegated leaf the fungus possibly dies because of the lack

of nutrients. Its progress cannot be great since hypersensitive necrotic lesions seldom occur on such leaves. In moderately or mildly variegated leaves, a few sori were observed but usually only in those regions where some chlorophyll was present. A seriously variegated plant was recorded as resistant even though genotypically it may have acked the gene responsible for resistance observed in nonvariegated plants.

Of 60 families (table 5) derived from resistant plants inoculated with race 6 in F_2 and inoculated with the same race in F_3, 19 were homozygous for resistance and 41 segregated in a ratio of 3 resistant plants to 1 susceptible. The deviation from the calculated 1:2 ratio of pure-breeding resistant to segregating families derived from F_2 resistant plants was not significant. The χ^2 value is 0.075,[10] which proves a very good fit to this ratio. Among the 19 homozygous resistant families, 3 plants of 598 were susceptible, which possibly resulted from seed mixture.

Of 41 heterozygous resistant families (table 5) with a total population of 1,844 plants, 175 were severely variegated. In many of the progenies where variegation occurred, the number of susceptible plants was slightly below the calculated 3 : 1 ratio. It is not assumed that the deficiency in numbers of susceptible plants was due in all cases to the presence of variegated plants. There was a deficiency, or a −46 deviation, of susceptible plants from the calculated number for a 3 : 1 ratio. The total χ^2 value for this ratio was 42.824 [11] for 41 degrees of freedom, which shows a nonsignificant deviation from a 3 : 1 ratio. The value of χ^2 when computed for the total population of the 41 families was 6.12,[10] which does not indicate a good fit for a 3 : 1 ratio. Twenty-seven of the 41 heterozygous families showed an insufficient number of susceptible plants, which in most cases was due to the presence of variegation. Only 1 family showed a slight significant deviation, but due to the accumulation of deficient numbers of susceptible plants, the χ^2 value of the totals of the tested families fitted a 3 : 1 ratio rather poorly. It is possible that the deviation would have been smaller had there been no variegated plants.

The F_2 susceptible plants did not produce 100-percent susceptibility in F_3. Of a total of 305 plants from 7 families, 22 plants were resistant. All but 1 of these were variegated, from which it is assumed that the lack of true breeding was the result of this chlorophyll deficiency. In 1 family 3 plants were resistant and 2 of these were variegated. The resistant nonvariegated plant may have escaped inoculation or it may have resulted from seed mixture.

The reason for the lack of infection of variegated plants is not definitely known. It may be due to a purely physiologic reaction of the host and fungus or to modifying genetic factors.

The data given above in some respects fail to corroborate those of the F_2 generation, indicating that resistance to physiologic race 6 may not be governed by a single dominant factor. If certain modifying factors are responsible for the lack of true breeding of the variegated plants, more than a single factor may govern the inheritance in the hybrids tested with this race.

[10] 5-percent point = 3.841.
[11] Equals 40-percent point.

Rust Race 12

Thirty-seven families (table 6) derived from the F_2 resistant as well as 17 from the susceptible class were inoculated in the F_3 generation. Fourteen of the 37 families were homozygous for resistance and 23 segregated in a ratio of 3 resistant plants to 1 susceptible. The deviation from the calculated 1 : 2 ratio of homozygous resistant to heterozygous resistant families was nonsignificant with a χ^2 value of 0.34.[12]

Table 6.—*Reaction to physiologic race 12 of F_3 progenies descended from F_2 hybrids inoculated with the same race*

Classification in F_2 generation	Families tested	Plants inoculated					
		Total	Resistant	Susceptible			
				Total	Grade—		
					5	6–7	8–9
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
Homozygous resistant (0 grade)	14	619	619	0			
Heterozygous resistant:							
Observed [1]	23	1,034	[2] 772	262	124	41	97
Calculated 3:1 ratio			775.5	258.5			
Homozygous susceptible	17	854	0	854	406	201	247

[1] Total χ^2 of individual progenies was 12.239; 5-percent point=35.172. χ^2 for total of each phenotype in all families was 0.063; 5-percent point=3.841.
[2] Resistance grade 0, in 20 families; and grade 3, in 3 families.

The susceptible plants (table 6) in both the heterozygous and homozygous susceptible classes are divided into three grades, i. e., one grade including plants showing extreme susceptibility, approximately as exhibited by the F_2 plants (fig. 5, *D*), and two lower grades. The conditions at the time the F_3 families were inoculated were not as favorable as when the F_2 plants were tested, from which it is assumed that some of this variability may have been due to a lack of favorable environmental conditions for the best development of the rust fungus and host. It is noted (table 6), however, that the segregation of the heterozygous resistant families into 3 resistant plants to 1 susceptible is a good fit to a 3:1 ratio. Three families showed a grade 3 resistance (fig. 5, *E*) and others complete immunity. If the infection had been slightly higher, these three families might possibly have been classed as homozygous susceptible with the assumption that an error had been made in the classification of the F_2 plants. On the other hand, with the extreme difference between a grade 3 rating as shown by 75 percent of the plants in these three families, and a grade 8 to 10 rating as exhibited by 25 percent, it hardly appears likely that any serious error in classification could have occurred.

All of the 17 F_2 homozygous susceptible families were 100 percent susceptible in F_3.

No. 192–48, the resistant parent of the crosses inoculated with race 12 gave a 0 reaction (table 2), whereas in the F_2 the resistant plants gave a grade 1 reaction (fig. 5, *C*). This slight variation may have been due to the environment. On the other hand, the grade 3 reac-

[12] 5-percent point=3.841.

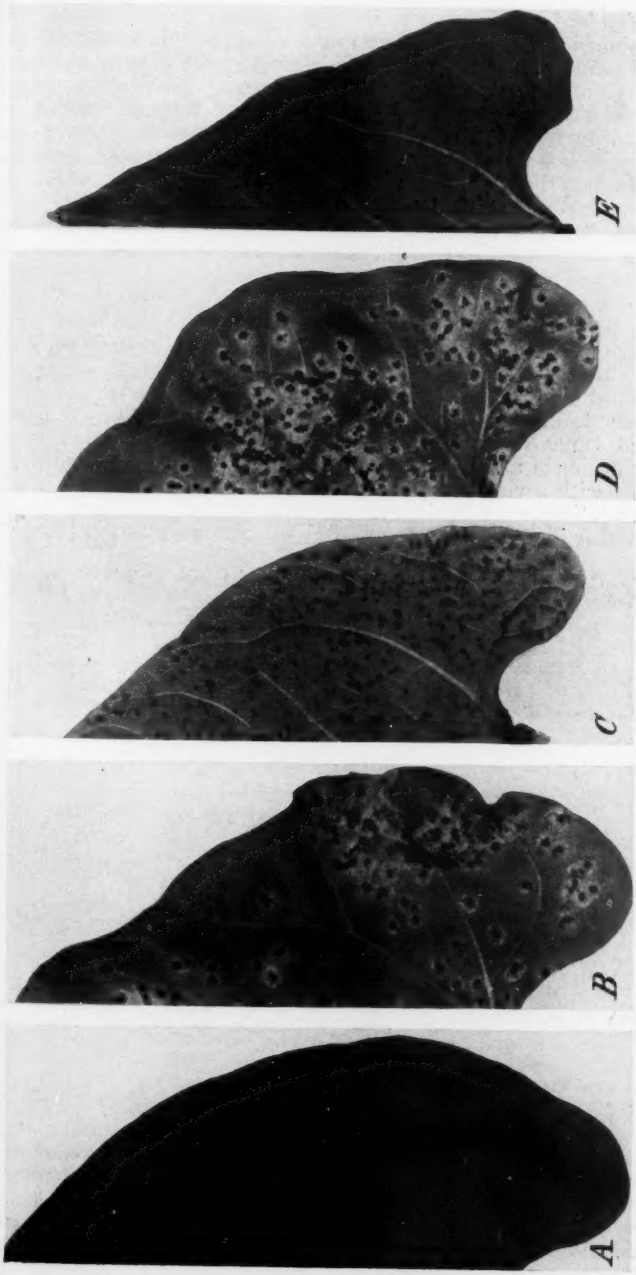


FIGURE 5.—Host reaction to race 12: *A*, Grade 0 on No. 192–48; *B*, grade 10 on Pinto; *C*, grade 1 on F_2 hybrid of cross Pinto × No. 192–48; *D*, *E*, grades 10 and 3, respectively, on other hybrids of same cross.

tion shown by the plants in the above-mentioned three families cannot be explained in this manner. Neither is one justified in assuming that all of the variations in the susceptible class (table 6) were due to environment alone. It is possible that a major genetic factor may govern the range of resistance from 0 to 4, and another, the range of susceptibility from 5 to 10. Clark (*1*), who apparently observed a similar phenomenon in his studies of the inheritance of stem rust and bunt in spring wheat crosses, stated that the effect of minor and modifying factors cannot always be distinguished from the effect of environment. The modifying factors alone or combined with the influence of environment might tend to induce variable degrees of resistance and susceptibility in certain families, but not to the extent that they would be grouped into any except a major resistant or susceptible class. This could account for the facts (1) that some of the heterozygous families did not show the same type of resistance and susceptibility at all times and (2) that the homozygous susceptible families did not exhibit the same degree of susceptibility.

In order to determine, if possible, the reason why the F_3 progenies exhibited types of resistance and susceptibility not noted in F_2, another F_2 line of identical parentage was tested and compared simultaneously with several F_3 progenies derived from resistant F_2 plants. The inoculations were made under more favorable conditions but not quite as near ideal as when the first F_2 families were tested (table 7).

TABLE 7.—*Comparison of reactions of F_2 progenies with certain F_3 progenies derived from previously tested F_2 plants that were resistant to race 12*

Classification, generation, and progeny No.	Plants inoculated									χ^2 of individual progenies
	Total	Resistant				Susceptible				
		Total	Grade—			Total	Grade—			
			0	2	3–4		5	6	8–10	
	No.	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	
F_3 progeny, 1229–1:										
Observed	171	129	104	19	6	42	20	10	12	[1] 0.017
Calculated 3:1 ratio	-----	128.25	----	----	----	42.75	----	----	----	-----
Homozygous resistant F_3 progenies:										
1227–4–81	80	80	80	0	0	0	----	----	----	-----
1227–4–85	44	44	0	0	44	0	----	----	----	-----
Heterozygous resistant F_3 progenies:										
1227–4–76	55	42	42	0	0	13	13	0	0	.056
1227–4–79	48	35	35	0	0	13	0	0	13	.111
1227–4–168	26	16	0	0	16	10	0	0	10	2.513
1227–4–175	40	30	0	0	30	10	0	0	10	0
1227–4–181	30	22	0	22	0	8	0	0	8	.044
Total:										
Observed	199	145	77	22	46	54	13	0	41	[2] 2.724
Calculated 3:1 ratio	-----	149.25	----	----	----	49.75	----	----	----	-----

[1] 5-percent point=3.841.
[2] 5-percent point=11.07. χ^2 calculated on total of each phenotype in all families was 0.484, for which the 5-percent point was 3.841.

The F_2 progeny 1,229–1 (Pinto × No. 192–48) segregated into 3 classes of resistance and 3 of susceptibility (table 7) and showed a good fit to a 3:1 ratio. Two F_3 families were homozygous for resistance, 1 showing total immunity and the other a grade 3 to 4 reaction. Five families with a total of 145 plants of different degrees

of resistance plus 54 of several degrees of susceptibility were heterozygous for resistance. The deviation is not significant and the value of χ^2 is 2.724 for 5 degrees of freedom, proving a very good fit to a 3:1 ratio.

The results indicate that actually several types of resistance and susceptibility to race 12 may occur. Why they were not recognized in the F_2 plants inoculated earlier (table 3) is not known, but it is likely that they were masked because of the environment and appeared only under conditions thus far not exactly determined.

Rust Race 11

The F_2 hybrids inoculated with rust race 11 (table 4) segregated in a ratio of 1 resistant to 2 intermediate to 1 susceptible plant (fig. 6, *C, E, F*). Twenty families in the F_3 generation, derived from previously tested F_2 resistant plants, were inoculated with the same race used in F_2, and all were found to be resistant but not to the same degree as in the F_2 generation. The resistant plants were grouped into four classes (table 8) and in only a few instances did all of the plants in any one family fall into the same class. Twelve progenies fell within either 1 or 2 groups and eight progenies within 4. The progenies that fell within 1 or 2 groups were inoculated under different environmental conditions from those that were grouped into 4 classes.

Table 8.—*Reaction to physiologic race 11 of F_3 families descended from F_2 plants inoculated with the same race*

Classification in F_2 generation	Families tested	Plants inoculated							
		Total	Resistance grade—					Susceptibility grade—	
			0	1	1–2	2–3	4	5–6	8–10
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
Homozygous resistant (grade 1)	20	1,377	710	469	0	120	78	0	0
Heterozygous resistant (grade 5–6):									
Observed [1]	27	1,769	0	0	452	0	0	891	426
Calculated 1:2:1 ratio					442.2			884.4	442.2
Homozygous susceptible (grade 10)	10	503	[2] 2	0	0	0	0	0	501

[1] Total χ^2 of individual progenies was 22.633 and the 5-percent point was 40.113. The χ^2 calculated for total of each phenotype in all families was 0.859 and the 5-percent point was 5.991.
[2] Possibly the result of seed mixture or of escape from inoculation.

Neither parent (table 2) of the crosses inoculated with race 11 showed a high degree of resistance. No. 780 (fig. 6, *A*), the more tolerant parent, gave a reaction of 6. The F_2 resistant progenies showed a transgressive segregation in that they were more resistant (fig. 6, *C*) than either parent, which would indicate that more than a single factor governed the inheritance of resistance to this race.

If it is assumed that the range of resistance in the F_2 homozygous resistant class could vary no further than from 0 to 2, depending on environmental conditions, it would be difficult to explain on this basis the extreme variability of resistance such as was found in the F_3 homozygous resistant families. Possibly it may be explained according to the theory mentioned earlier with regard to race 12, that is,

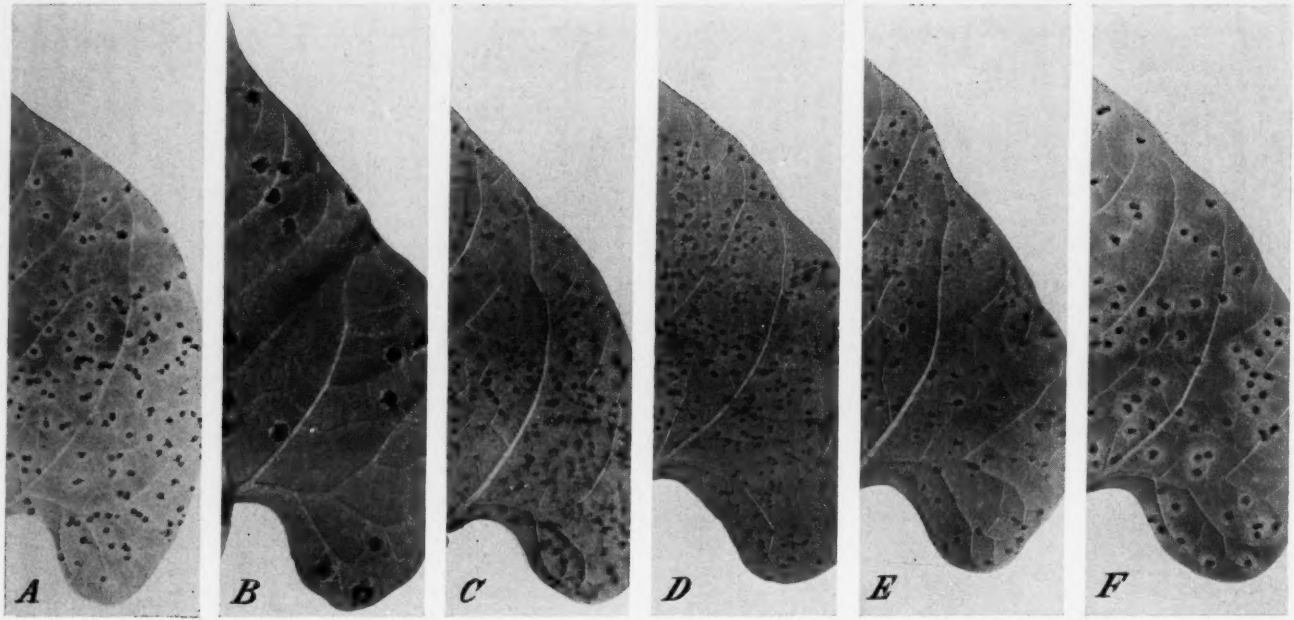


FIGURE 6.—Host reaction to race 11: *A*, Grade 6 on No. 780; *B*, grade 10 on Pinto; *C*, grade 1 on F_2 hybrid of cross Pinto × No. 780; *D*, *E*, *F*, grades 3 to 4, 4 to 5, and 10, respectively, on other hybrids of same cross. Note that necrotic lesions in *C* are larger than in *D* and *E*, but they contained no spores.

that a major dominant gene might be responsible for the range of resistance from 0 to 4 and that minor modifying factors which may differ in amount and effect might be responsible for the other types of resistance shown in the several F_3 homozygous resistant families.

Twenty-seven heterozygous families that showed an intermediate reaction in F_2 segregated in a 1:2:1 ratio in F_3 (table 8), showing that the 3 F_2 generation classes were distinct. The range of resistance was not as variable as it was in the homozygous resistant families, which made it less difficult to separate the plants within a family into their proper classification. Why little, if any, variability occurred in these families as compared with the homozygous resistant families is uncertain. Both classes were inoculated at the same time and under identical environmental conditions. Of 1,769 plants inoculated in the 27 families (table 8), 452 were resistant, 891 intermediate, and 426 susceptible. The χ^2 values shown in table 8 indicate a good fit to a 1:2:1 distribution.

In 10 homozygous susceptible families (table 8) 503 plants were tested and all except 2 were susceptible to approximately the same degree as in the F_2 generation. The 2 resistant plants occurred in separate families, and it is probable that they resulted from seed mixture but they may have escaped inoculation.

A few chlorophyll-deficient plants that differed in appearance from the variegated plants found in the 2 progenies inoculated with rust race 6 were observed in a number of tested F_3 families. These plants, although susceptible to the rust, did not exhibit nearly as high a degree of susceptibility as normal plants. In a few instances they gave a grade 6 reaction, whereas normal plants in the same family gave a grade 10 reaction. In several instances a grade 0 reaction was obtained in plants extremely deficient in chlorophyll. As only a small number of such plants were found in all of the families tested, they were not included in the ratios.

Rust Race 17

The F_2 hybrids inoculated with rust race 17 segregated in the same manner as those inoculated with race 12, and gave good fits to a 1:2:1 ratio (table 4).

Twelve F_2 homozygous resistant families (table 9) bred true for resistance in F_3. Thirty-nine heterozygous families which showed an intermediate reaction in F_2, segregated into 3 resistant plants to 1 susceptible, although theoretically the segregation should have been identical with that of the F_2, i. e., 1 resistant plant to 2 intermediate to 1 susceptible. The deviation from this ratio was nonsignificant since the value of χ^2 was 0.103, indicating a good fit to a 3:1 ratio. Two grades of resistance (fig. 7, *A* and *B*) were noted (table 9) as well as 2 grades of susceptibility (fig. 7, *C* and *D*). More plants were found in the 0 resistant grade than in grade 2; also, a larger number of plants were found in grade 7 susceptible than in grade 8 to 9.

It is believed that the failure to obtain a 1:2:1 segregation in the heterozygous families was due to a lack of the proper environment for the maximum development of the rust fungus. Only 86 of the 387 susceptible plants in the heterozygous resistant families (table 9) gave a grade 8 to 9 reaction instead of a grade 10 as they did in the F_2 (table 4). The same is true in the homozygous susceptible families,

where of a total of 897 plants, only 342 were rated grade 8 to 9 in susceptibility. It is assumed that if conditions had been optimum approximately two-thirds of the resistant plants in the heterozygous

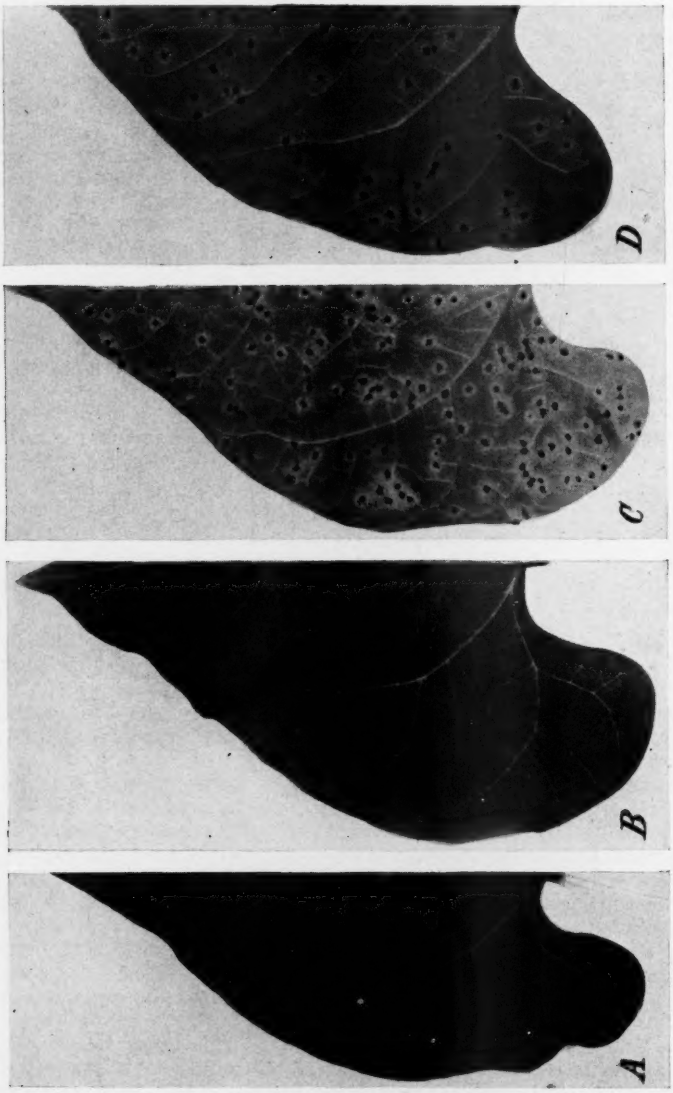


FIGURE 7.—Host reaction to race 17: *A*, Grade 0 on hybrid of cross Pinto × No. 192–48; *B*, *C*, *D*, grades 2, 7, and 10, respectively, on other hybrids of the same cross.

families would have given an intermediate reaction, substantiating the 1:2:1 ratio of the F_2. Instead, these plants fell within the resistant class, making a 3:1 ratio of resistance to susceptibility. The

23 homozygous susceptible families bred true for susceptibility, but the plants fell within 2 classes (table 9).

TABLE 9.—*Reaction to physiologic race 17 of F_3 families descended from F_2 plants that had been inoculated with the same race*

Classification in F_2 generation	Families tested	Plants inoculated						
		Total	Resistant			Susceptible		
			Total	Grade—		Total	Grade—	
				0	2		7	8–9
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
Homozygous resistant (grade 1)	12	409	409	409	0	0	0	0
Heterozygous intermediate (grade 5–6):								
Observed [1]	39	1,570	1,183	761	422	387	301	86
Calculated 3:1 ratio			1,177.5			392.5		
Homozygous susceptible (grade 10)	23	897	0	0	0	897	555	342

[1] Total χ^2 of individual families was 29.923, which=15-percent point. χ^2 calculated on total of each phenotype in all families=0.103; 5-percent point=3.841.

The F_3 inoculations were conducted at two different periods during the winter of 1939–40. Environmental conditions were less favorable when the first set was made than when the second set was made. The results, especially in the resistant class of the heterozygous families, clearly indicated this difference. In the first inoculations the results showed that of a total of 640 resistant plants, 625 fell within grade 0 and 15 within grade 2. Of a total of 543 plants, in the second inoculations, 136 fell within grade 0 and 407 within grade 2.

To study further the reason that the intermediate F_2 class failed to segregate in a 1:2:1 ratio in F_3, 2 untested F_2 families and 11 more F_3 families from tested F_2 lines that had produced an intermediate reaction were inoculated with race 17. The results are shown in table 10. The environmental conditions were slightly more favorable than when F_3 plants were tested earlier (table 9); however they were not as favorable as when the first F_2 families were inoculated (table 4). The data presented in table 10 do not appear to be sufficiently consistent to be interpreted on the basis of a one-factor pair difference. In progeny 1228–4, the intermediate class was slightly more resistant than the F_2 progenies listed in table 4. Two grades of susceptibility were produced, whereas in the earlier tested F_2 plants only a susceptible 10 grade was noted. On the other hand, if the plants in grade 3 are regarded as resistant F_2 progeny 1228–5 segregated in a 3:1 ratio. It is likely that the plants in grade 3 might have shown an intermediate reaction under a more favorable environment. Furthermore, it is possible that part of the plants in the 0 grade may have been genotypically intermediate in reaction but failed to reach that degree of development because of the unfavorable environment. On the other hand, environment alone may not have been responsible for the variability, but the reaction may have been influenced by certain modifying factors.

TABLE 10.—*Reaction of F_2 progenies and F_3 progenies descended from previously tested F_2 plants which had shown an intermediate reaction (grade 5–6) to physiologic race 17*

Generation and family No.	Families tested	Plants inoculated								Total χ^2 value of individual families [1]	
		Total	Resistant	Intermediate resistant			Susceptible			Calculated	5-percent point
				Total	Grade—		Total	Grade—			
					3	4		7–8	9		
F_2:	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*		
1228–4	1	113	31	48	0	48	34	13	2	2.722	5.991
1228–5	1	200	83	69	69	0	48	31	17	.107	3.841
F_3:											
Observed	11	497	132	254	254	0	111	96	15	[2]14.278	33.924
Calculated 1:2:1 ratio			124.25	248.5			124.25				

[1] Degrees of freedom = twice the number of families tested except for family 1228–5.
[2] χ^2 calculated on totals of each phenotype in all families = 2.018; 5-percent point = 5.991.

Four hundred ninety-seven F_3 plants derived from previously tested F_2 lines that had given an intermediate reaction were inoculated (table 10) with the result that 132 were found to be resistant, 254 intermediate, and 111 susceptible. If the plants in grade 3 are considered as intermediate in reaction then the total χ^2 value of the individual families for a 1:2:1 distribution is 14.278,[13] which shows a good fit for this ratio. The χ^2 value for the total population (2.023) also proves a good fit. The intermediate class showed a higher degree of resistance than did the earlier tested F_2 plants (table 4), which was assumed to be the result of the environment. In the previously tested F_3 progenies (table 9) a considerable number of plants in the families that gave an intermediate reaction in F_2 showed a grade 2 reaction. Many of these may have given an intermediate reaction under more favorable environmental conditions. Classification was difficult because of the similarity between these plants and those in the 0 class.

The susceptible plants were divided into 2 groups, the majority of which fell within the 7 to 8 grade. Many, if not all, of these plants might have attained a higher degree of infection had conditions been more favorable. On the other hand, minor or modifying factors may also have been responsible for certain of the plants not attaining the degree of infection that was shown by the F_2 plants. These same factors may have been the cause of the failure of the F_2 intermediate class of previous experiments to segregate in the expected 1:2:1 ratio in F_3.

DISCUSSION

It is evident from the data presented in this study that in the bean hybrids investigated a single genetic factor is involved in the inheritance of resistance to physiologic races 1 and 2 of bean rust, and that more than one factor may govern such inheritance to races 6, 11, 12, and 17. It is also shown that the factor for resistance is dominant

[13] 5-percent point = 33.924

in the hybrids inoculated with races 1, 2, 6, and 12, and incompletely dominant in the crosses inoculated with races 11 and 17.

No. 780, the less susceptible of the two parents of the crosses inoculated with race 11, exhibited (table 2) a grade 6 reaction (fig. 6, *A*), whereas Pinto, the more susceptible parent, showed a grade 10 reaction (fig. 6, *B*). In the F_2 generation, the plants in the homozygous resistant class were less susceptible (fig. 6, *C*) than No. 780, thereby indicating a transgressive segregation.

The inheritance of resistance to races 6, 11, 12, and 17, as previously mentioned, may be governed by more than a single gene even though the F_2 results indicate a single-factor difference. Although it is possible that the lack of infection among the chlorophyll-deficient plants inoculated with race 6 could be explained on a purely physiological basis, it is also likely that this phenomenon may have been due to minor or modifying factors.

An F_2 progeny closely related to those that were earlier inoculated with race 12 was later inoculated with the same race and a wide range of resistance and susceptibility was noted (table 7), although only one type of resistance was observed in the first test. All of the homozygous resistant F_3 plants inoculated with race 12, as well as the resistant plants of the heterozygous resistant families, did not breed true for the same type of resistance as shown in the F_2 plants (table 3) but exhibited a greater range of resistance. Similarly, the homozygous susceptible F_2 plants did not breed true in every case in the F_3 for the type of susceptibility exhibited in F_2 (tables 3 and 6). Likewise, not all of the plants in the homozygous resistant families inoculated with race 11 bred true for the same type of resistance as shown by the F_2 plants (table 4). Some but not all of this variation may have been caused by environment, and minor modifying factors may have been responsible to some extent. Why these types of resistance and susceptibility were not recognized in the earlier inoculated F_2 plants is difficult to explain. It is possible that an exacting environment not thus far recognized is essential for their production. There is likewise a possibility that a major gene may inhibit their production under most conditions.

The two grades of susceptibility recognized among the susceptible plants as well as the variability in the plants showing an intermediate reaction when inoculated with race 17 (tables 9 and 10) probably resulted from a combination of modifying genetic factors and environmental influences.

These studies showed that environment probably played an important role, as regards its influence both on the host and on the fungus, and this may explain, in part at least, why many of the readings taken under one set of conditions differed from those taken under another.

Hybrids inoculated with races 11 and 17, gave in F_2 (table 4) a ratio of 1 resistant plant to 2 intermediate to 1 susceptible. The plants that showed an intermediate reaction to race 11 in F_2 segregated in a similar manner in F_3 (table 8), whereas the plants in the same class inoculated with race 17 under the same environmental conditions segregated in 3 resistant plants to 1 susceptible (table 9). When the inoculations with race 17 were made under more favorable conditions, the intermediate class segregated in a 1:2:1 ratio in F_3 (table 10) as expected. The intermediate class, however, shifted from a grade

5 to 6 rating (table 4) to a grade 3 (table 10), and the susceptible class from a grade 10 rating (table 4) to grades 7 to 8 and 9 (table 10). This suggests that because of the unfavorable environment those plants that should have shown an intermediate reaction in the earlier F_3 tests appeared quite highly resistant and were classified with the homozygous resistant plants. The combination of these two classes compared with the homozygous susceptible class gave a 3:1 ratio, which indicates that the environment may definitely affect the results and may play a more important role with some races than with others.

These data have convinced the writers that certain uncontrollable differences in environment, even though slight, may be sufficient to shift the degree of infection into lower grades than would normally be expected. It was not deemed advisable to adhere at all times to an arbitrary standard of classification. It has been necessary to take into account all the factors that were known to influence the results before assigning infected material to the different classes. The writers believe that these records of actual occurrence may be of benefit to other investigators who may note similar phenomena in their experiments.

It is not known how many of the 11 grades used in classifying the degree of resistance and susceptibility may be governed by a single gene. Three general classes have been recognized, that is, resistant, intermediate, and susceptible, and within these other subclasses were noted.

It should be remembered that the results presented herein deal only with the inheritance of resistance in the seedling stages of growth under greenhouse conditions. Earlier studies by Stakman (*12*), Melchers and Parker (*10*), and Hayes, Stakman, and Aamodt (*8*) with the stem rust of wheat showed that certain varieties and hybrids of wheat in the seedling stage showed relatively high susceptibility under greenhouse conditions but considerable resistance as adult plants in the field. It was also shown by Goulden, Neatby, and Welsh (*4*) that resistance in the mature stage was inherited independently of seedling resistance, and they concluded that the two types of resistance are distinct. Levine and Smith (*9*), working with races of oat rust (*Puccinia graminis avenae* Eriks.), found close agreement in the reactions of seedling and maturing plants. This phase of the bean rust problem has not been investigated, but observations have indicated that many varieties susceptible in the maturing stages in the field are equally as susceptible in the seedling stage in the greenhouse.

At the present time relatively few commercial varieties of either the garden or the field types are resistant to many of the races. However, there are a few that have shown a high degree of resistance to a number of the races thus far described. The writers have employed some of these varieties in certain crosses, and a number of hybrids resistant to 17 races are now being developed.

SUMMARY

Four different crosses involving six varieties or strains of beans and six physiologic races of bean rust were investigated to determine the mode of inheritance of resistance. The races of rust involved were 1, 2, 6, 11, 12, and 17.

Results proved that resistance to races 1 and 2 in the bean hybrids investigated was due to a single Mendelian factor. Possibly other genetic factors may be involved in the resistance of the hybrids inoculated with races 6, 11, 12, and 17. Resistance was shown to be dominant in the hybrids inoculated with races 1, 2, 6, and 12, and incompletely dominant in those inoculated with races 11 and 17.

Severely variegated plants inoculated with race 6 showed immunity, whereas those mildly variegated showed a lesser degree of susceptibility than normal plants. This may have been due either to the physiological behavior of the host and the fungus, or to modifying genetic factors, or to a combination of these.

It is possible that a major gene may govern resistance within grade 0 to 4 in the hybrids inoculated with races 11 and 12, and a similar factor susceptibility within grade 5 to 10. Minor modifying factors may be responsible for the variable degrees of resistance and susceptibility found within the major classes.

An F_2 line related to those progenies previously inoculated with race 11 showed several classes of resistance and susceptibility not previously observed, which explains in part at least the reason for the presence of these variable classes in F_3.

Transgressive segregation occurred in the hybrids inoculated with race 11 since one-fourth of the F_2 plants showed more resistance than the less susceptible parent.

The results with the F_3 progenies inoculated with race 17 showed that environment exercised some influence on the degree of infection in the intermediate class. Under an unfavorable environment the plants appeared resistant and segregated in a ratio of 3 resistant to 1 susceptible, whereas under more favorable conditions they segregated in a 1:2:1 ratio.

These data deal only with the inheritance of resistance of seedling plants grown under greenhouse conditions.

LITERATURE CITED

(1) Clark, J. Allen.
1933. inheritance of stem rust and bunt reactions in spring wheat crosses. World's Grain Exhib. and Conf., Regina, Canada, Proc. 2: 37–43.

(2) ——— and Smith, Glenn S.
1935. inheritance of stem-rust reaction in wheat, ii. Amer. Soc. Agron. Jour. 27: 400–407.

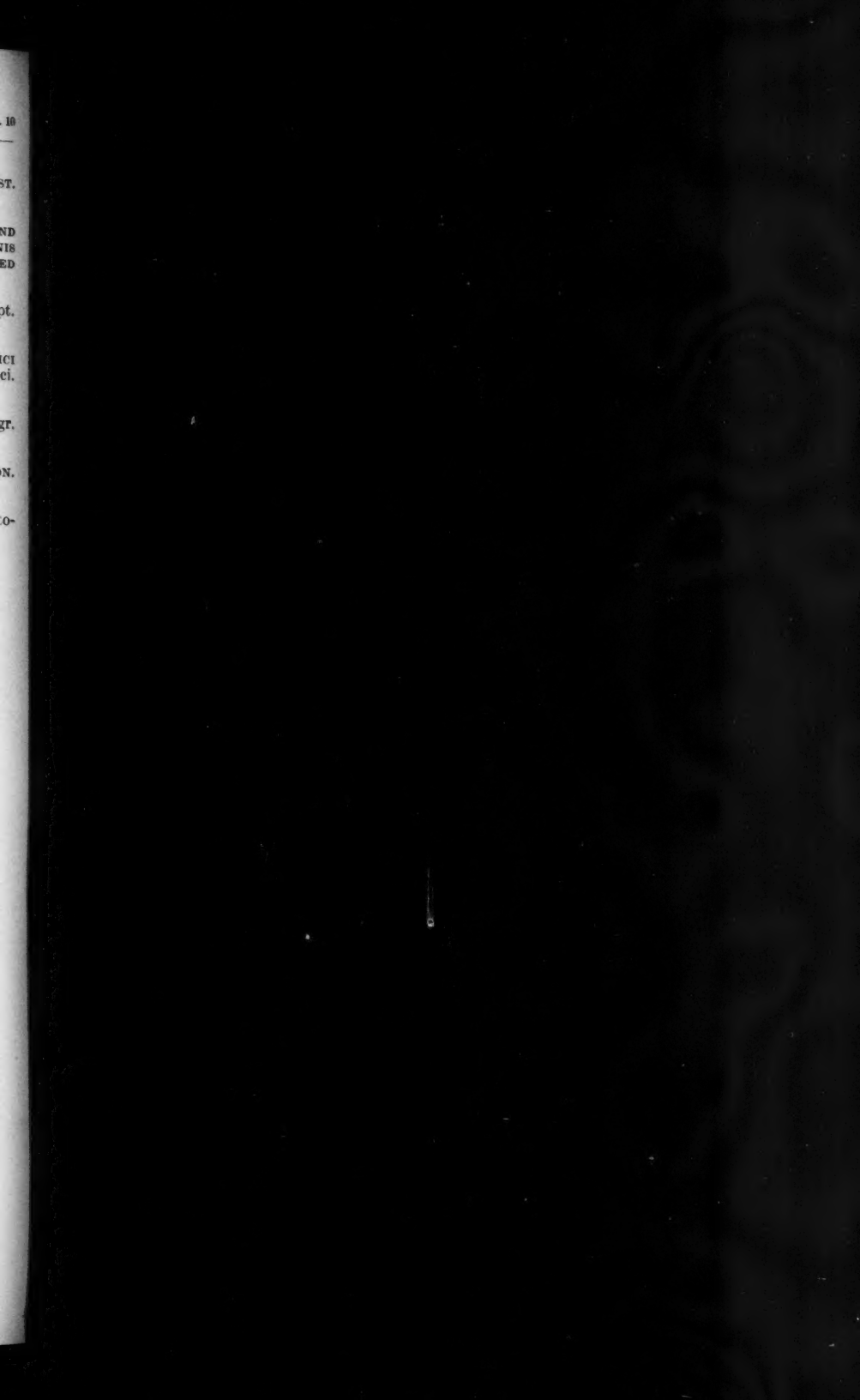
(3) Fisher, R. A.
1936. statistical methods for research workers. Ed. 6, rev. and enl., 339 pp., illus. Edinburgh and London.

(4) Goulden, C. H., Neatby, K. W., and Welsh, J. N.
1928. the inheritance of resistance to puccinia graminis tritici in a cross between two varieties of triticium vulgare. Phytopathology 18: 631–658, illus.

(5) Harter, L. L.
1939. physiologic races of the fungus causing bean rust. (Abstract) Phytopathology 29: 9.

(6) ——— Andrus, C. F., and Zaumeyer, W. J.
1935. studies on bean rust caused by uromyces phaseoli typica. Jour. Agr. Res. 50: 737–759, illus.

(7) ——— and Zaumeyer, W. J.
1941. differentiation of physiologic races of uromyces phaseoli typica on bean. Jour. Agr. Res. 62: 717–731, illus.

(8) HAYES, H. K., STAKMAN, E. C., and AAMODT, O. S.
1925. INHERITANCE IN WHEAT OF RESISTANCE TO BLACK STEM RUST. Phytopathology 15: [371]–387, illus.
(9) LEVINE, M. N., and SMITH, D. C.
1937. COMPARATIVE REACTION OF OAT VARIETIES IN THE SEEDLING AND MATURING STAGES TO PHYSIOLOGIC RACES OF PUCCINIA GRAMINIS AVENAE, AND THE DISTRIBUTION OF THESE RACES IN THE UNITED STATES. Jour. Agr. Res. 55: 713–729, illus.
(10) MELCHERS, LEO E., and PARKER, JOHN H.
1922. RUST RESISTANCE IN WINTER-WHEAT VARIETIES. U. S. Dept. Agr. Bul. 1046, 32 pp., illus.
(11) NEATBY, K. W., and GOULDEN, C. H.
1930. THE INHERITANCE OF RESISTANCE TO PUCCINIA GRAMINIS TRITICI IN CROSSES BETWEEN VARIETIES OF TRITICUM VULGARE. Sci. Agr. 10: 389–404, illus.
(12) STAKMAN, E. C.
1914. A STUDY IN CEREAL RUSTS: PHYSIOLOGICAL RACES. Minn. Agr. Expt. Sta. Bul. 138, 56 pp., illus.
(13) WINGARD, S. A.
1933. THE DEVELOPMENT OF RUST-RESISTANT BEANS BY HYBRIDIZATION. Va. Agr. Expt. Sta. Tech. Bul. 51, 40 pp., illus.
(14) ZAUMEYER, W. J.
1938. A HERITABLE ABNORMALITY OF BEANS RESEMBLING MOSAIC. (Phytopath. Note.) Phytopathology 28: 520–522.

U. S. GOVERNMENT PRINTING OFFICE: 1941